Mixed lubrication analysis of vane sliding surface in rotary compressor mechanisms

- Influences of friction of vane sliding surface on lubricating condition between vane top and rolling piston -

Air -conditioner

Rotary Compressor

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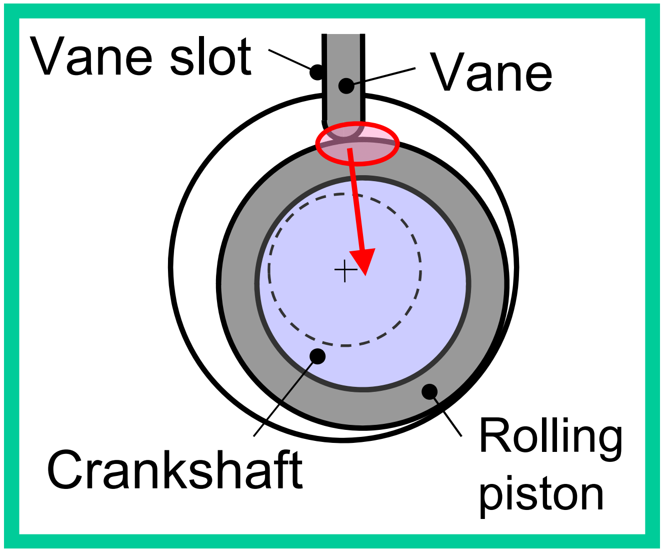
Background and Purpose



Compression mechanism

Air-conditioner

Rotary Compressor

Background

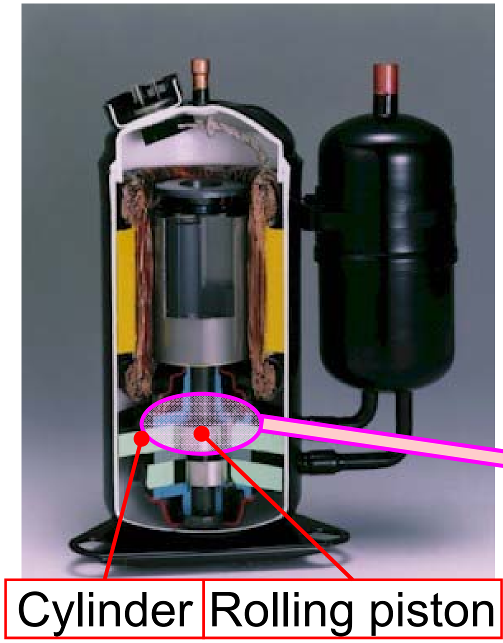
- Lubricating condition between rolling piston and vane top is very severe.
- It is important to clarify characteristics of motion and to improve lubricating condition between rolling piston and vane.
- Mixed lubrication analysis of vane sliding surface between vane and vane slot is required to accurately obtain normal force acting on piston.

Purpose

- To investigate lubricating characteristics between rolling piston and vane

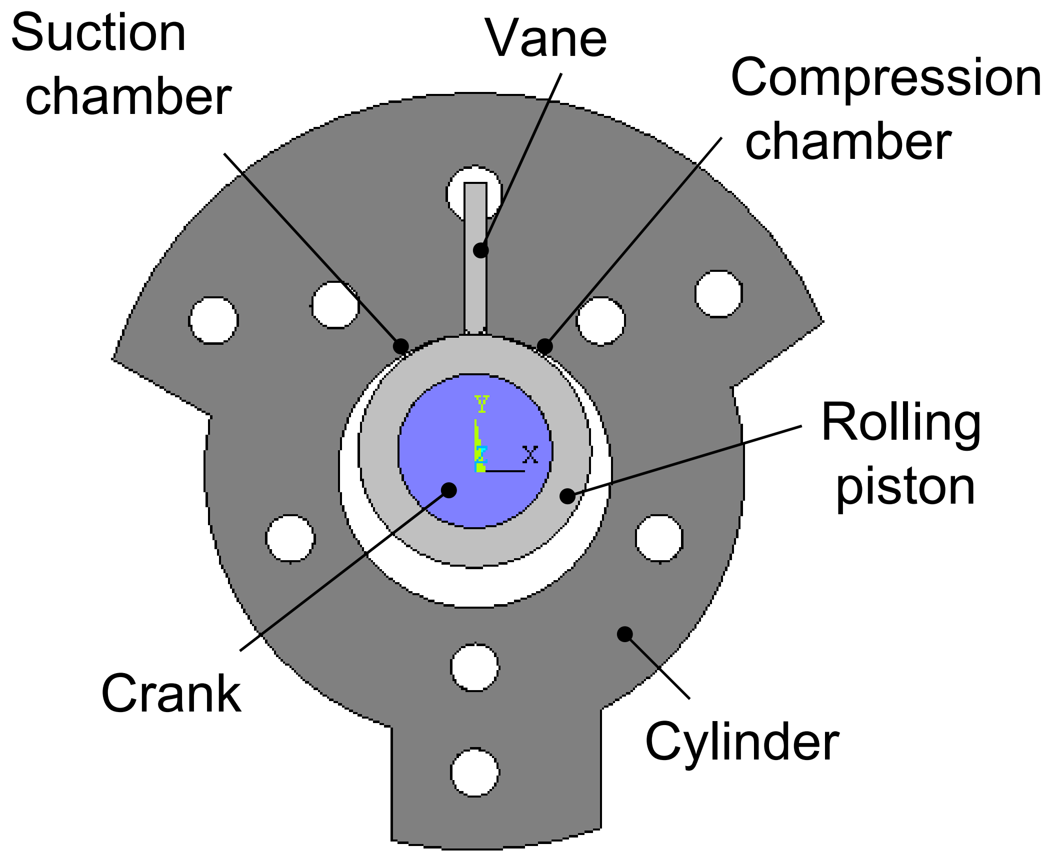
We have performed numerical analysis of motion of rolling piston and vane considering mixed lubrication of vane sliding surface.

Compression Mechanism in rotary compressor



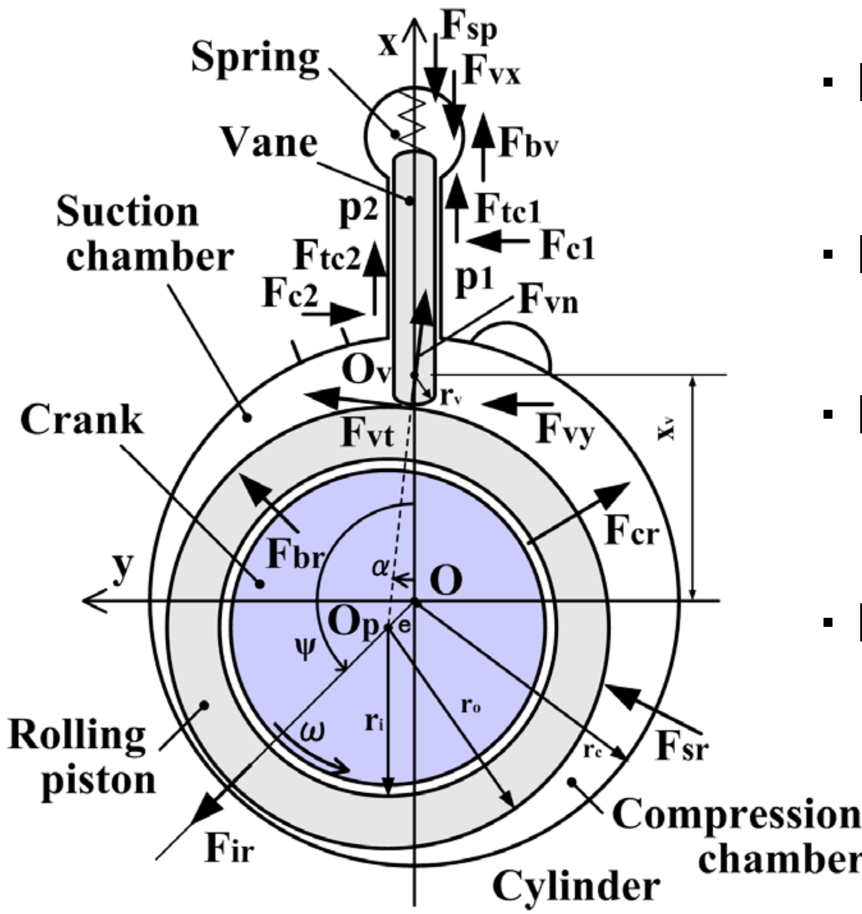
Rotary Compressor

Air- conditioner



Compression mechanism

Motion of vane and rolling piston in the x- and y-directions



Static coordinate system
with origin O at cylinder center

- Equation of motion of vane

$$m_v \ddot{x}_v = F_{vnx} + F_{vtx} + F_{to1} + F_{to2} + F_{tc1} + F_{tc2} + F_{bv} - F_{vx} - F_s$$

- Equation of equilibrium of forces of vane

$$0 = F_{vny} + F_{vty} + F_{o1} - F_{o2} + F_{c1} - F_{c2} + F_{vy}$$

- Equation of equilibrium of moments of vane

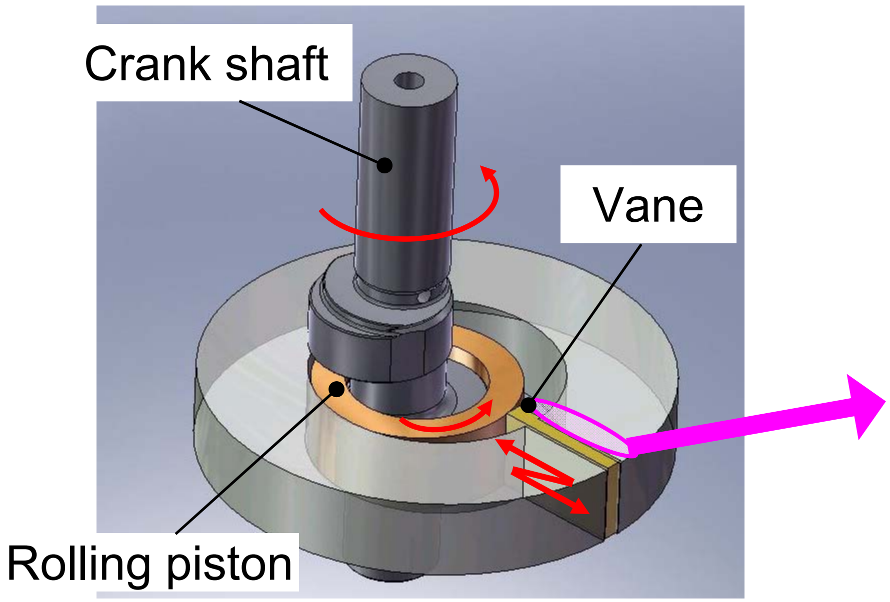
$$0 = M_{vn} + M_{vt} + M_{o1} + M_{o2} + M_{c1} + M_{c2}$$

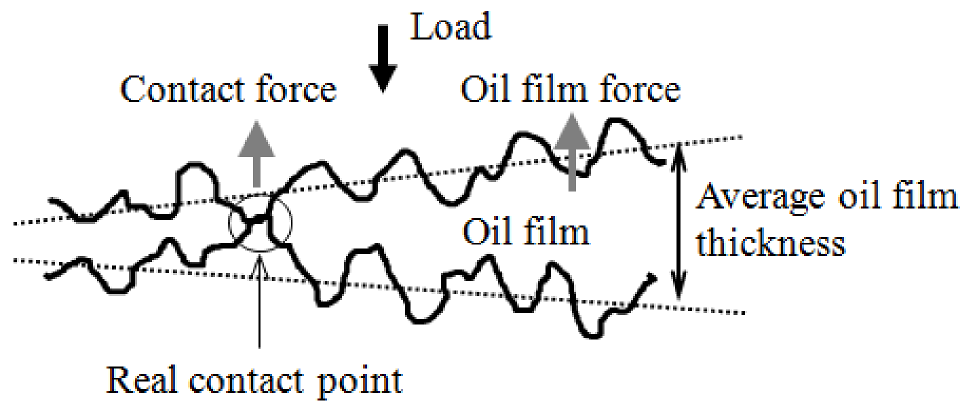
- Equation of equilibrium of forces of rolling piston

$$0 = F_{crx} + F_{srx} + F_{brx} - F_{irx} - F_{vnx} - F_{vtx}$$

$$0 = -F_{cry} + F_{sry} + F_{bry} + F_{iry} + F_{vny} - F_{vty}$$

Mixed lubrication analysis of vane sliding surface between vane and vane slot





Model of mixed lubrication on vane sliding surface

We have used mixed lubrication analysis theory.

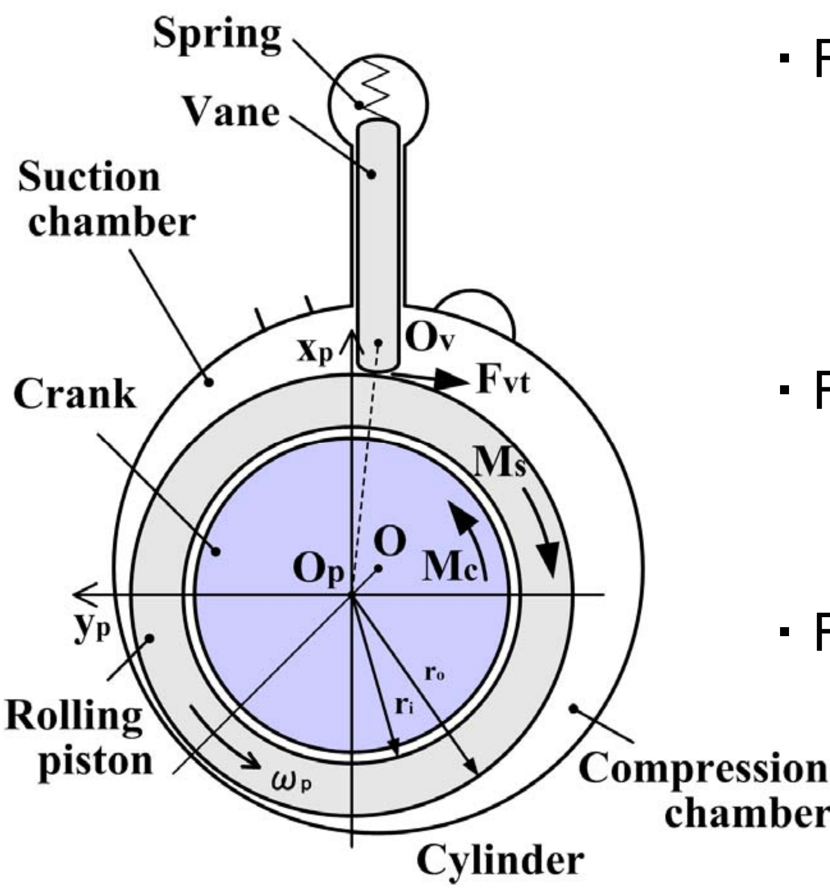
- Modified Reynolds equation

$$\frac{\partial}{\partial x}\left(\Phi_X \frac{\bar{h}^3}{\eta}\frac{\partial p}{\partial x}\right) = 6U\frac{\partial h_T}{\partial x} + 6U\sigma\frac{\partial \Phi_s}{\partial x} + 12\frac{\partial h_T}{\partial t}$$

- Elastic contact equation

$$p_c = k_c E' \times 4.4086 \times 10^{-5}\left(4 - \frac{\bar{h}}{\sigma}\right)^{6.804}$$

Motion of rolling piston in rotation direction



Moving coordinate system
with origin Op at crank center

- Rotational equation of motion of rolling piston about piston center Op

$$I\dot{\omega}_p = M_r - M_s - r_o F_{vt}$$

- Friction force acting on piston at vane contact

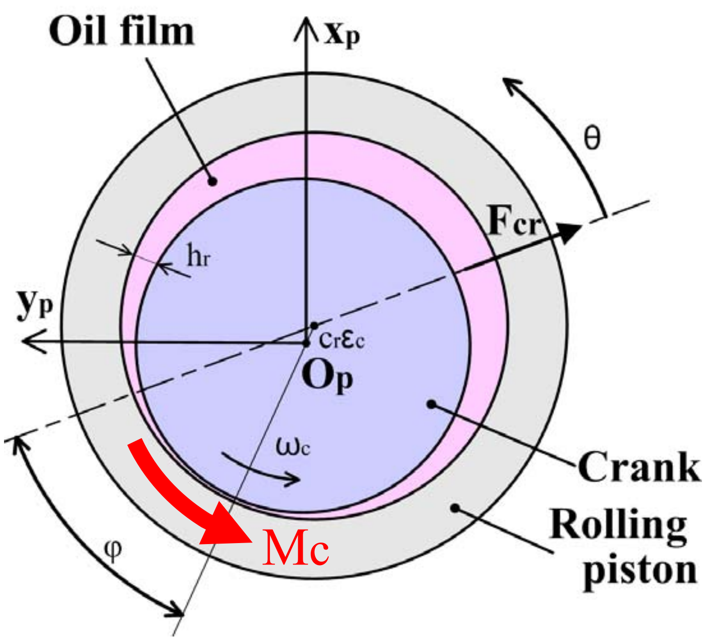
Fvt is calculated by Coulomb's law

$$F_{vt} = \gamma_1 \mu_p F_{vn}$$

- Friction moments on both end surfaces of rolling piston

$$M_s = \frac{2\pi\eta\omega_p\left(r_o^{\,4} - r_i^{\,4}\right)}{c_s}$$

Friction moment due to oil film viscosity between piston and crank



Analysis model of oil film between piston and crank

- Reynolds equation of oil film between piston and crank

$$\frac{\partial}{r_i^2 \partial\theta}\left(\frac{h_r^3}{\eta}\frac{\partial p_r}{\partial\theta}\right)+\frac{\partial}{\partial z}\left(\frac{h_r^3}{\eta}\frac{\partial p_r}{\partial z}\right)=6\omega_c\frac{\partial h_r}{\partial\theta}+12\frac{\partial h_r}{\partial t}$$

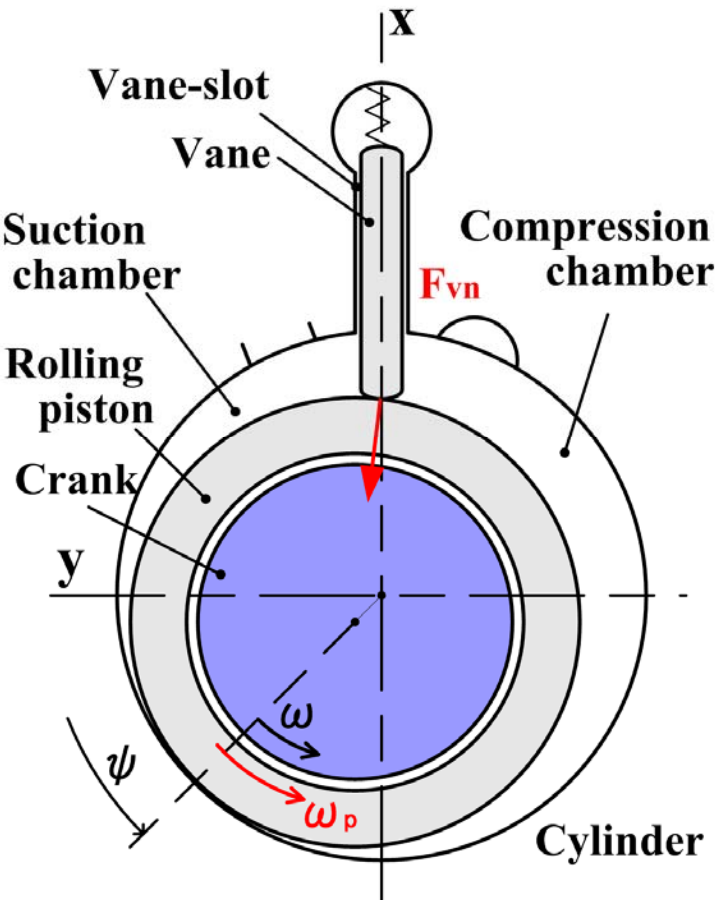
Oil film thickness between piston and crank

$$h_r = c_r \times \left(1+\varepsilon_c \cos(\theta-\varphi)\right)$$

- Friction moment due to oil film viscosity

$$M_r = \int\int\left(\frac{\eta\omega_c r_i}{h_r}+\frac{h_r}{2r_i}\frac{\partial p_r}{\partial\theta}\right)r_i^2\, d\theta dz$$

Analysis procedure

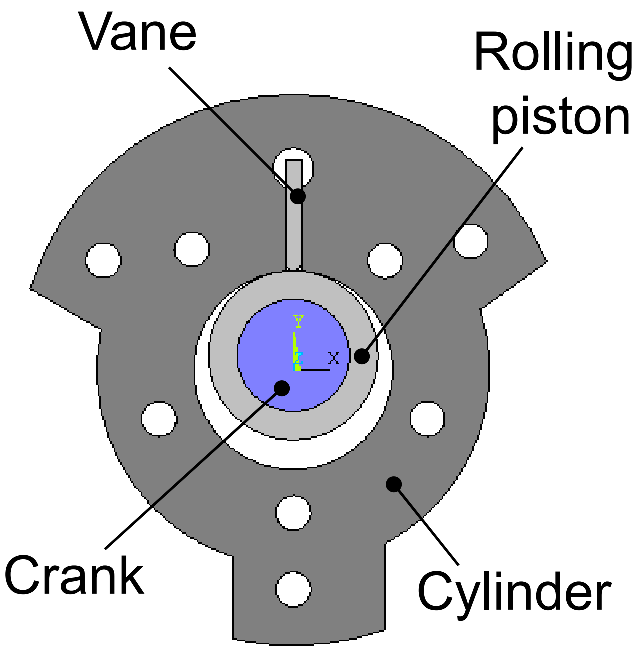


Brief drawing of compression mechanism in rotary compressor

- Equations are solved as a coupled problem.
- We calculate normal force acting on piston at vane contact F_{vn} and angular velocity of piston rotation ω_p .

- This analysis is calculated recursively along the time axis.

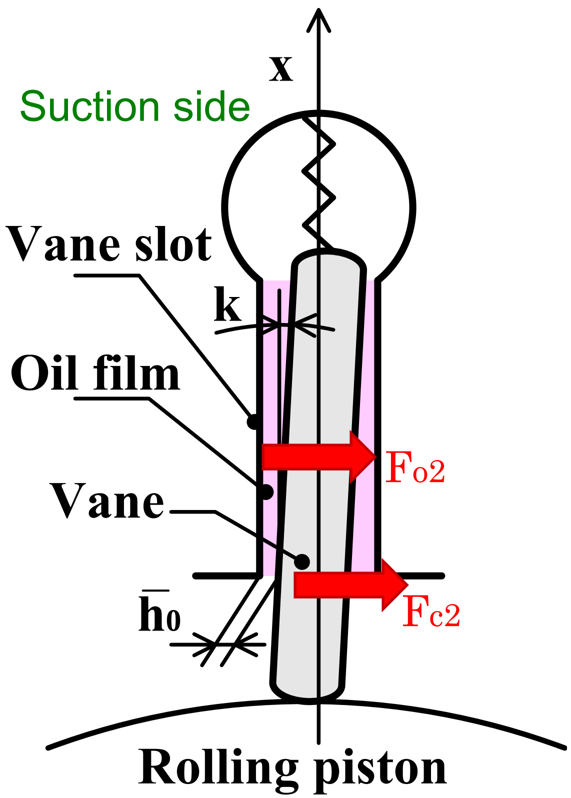
Analysis condition



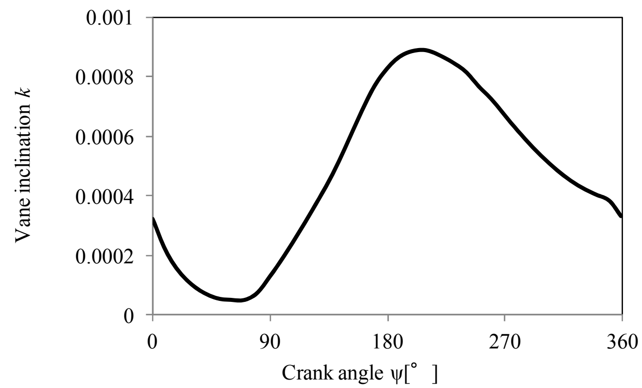
Compression mechanism

Radius of cylinder [mm]	36.5
Outer radius of piston [mm]	29.7
Inner radius of piston [mm]	20.0
Eccentricity of crank [mm]	6.8
Oil viscosity, η [10^{-3} Pa・s]	2.8
Rotating Frequency, f_0 [Hz]	60
Friction coefficient at solid contact between vane and vane slot, μ_v	0.0, 0.10, 0.20, 0.30, 0.40
Friction coefficient between piston and vane, μ_p	0.12

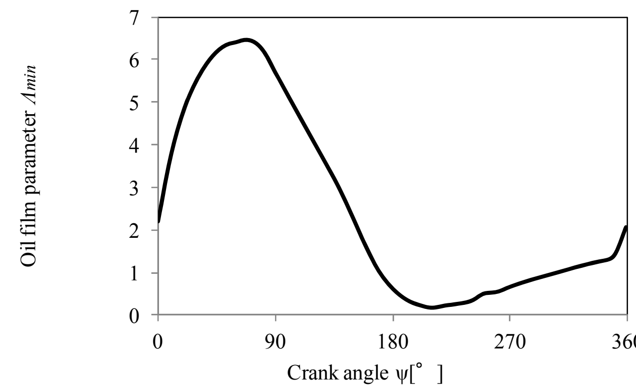
Analysis result
Lubrication characteristics of vane sliding surface



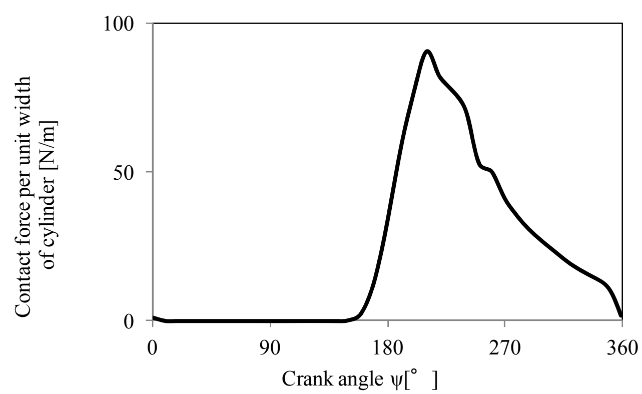
Schematic view of vane circumference



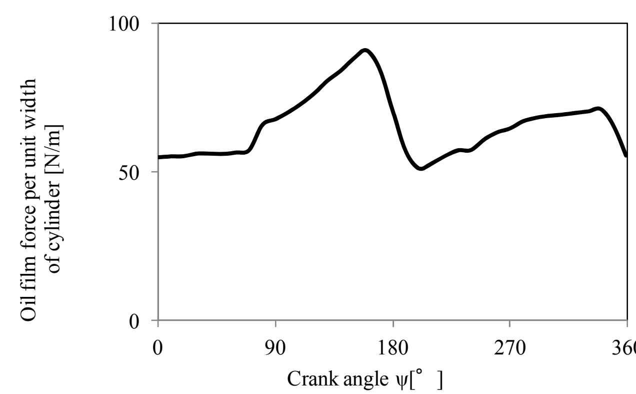
Inclination of vane k



Minimum oil film parameter of vane sliding surface Λ_{min}(=h_{min}/σ

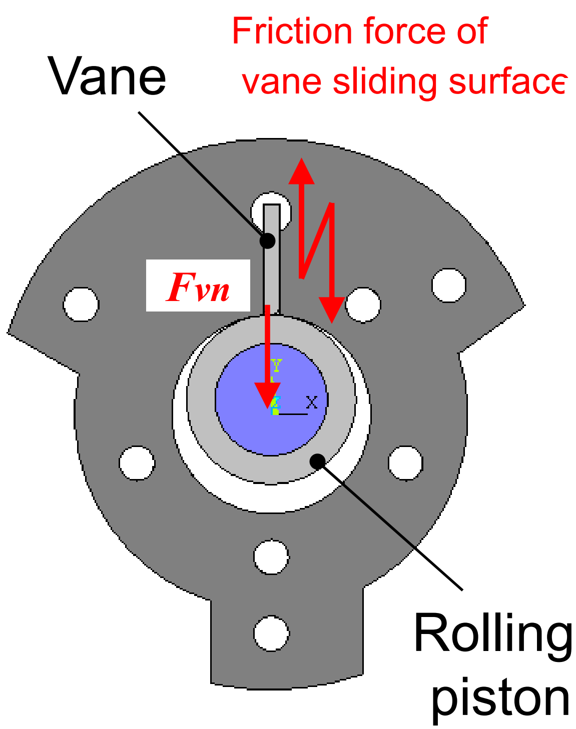


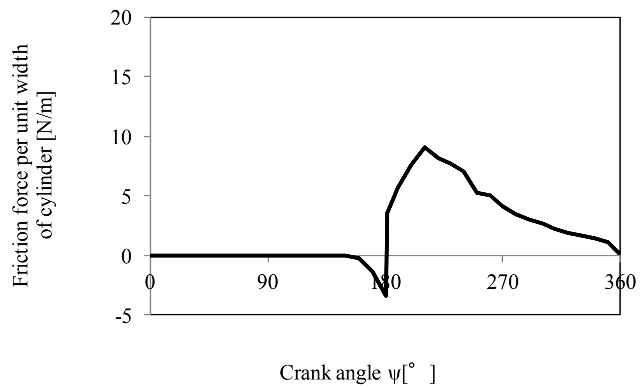
Contact force of vane sliding surface F_{c2}



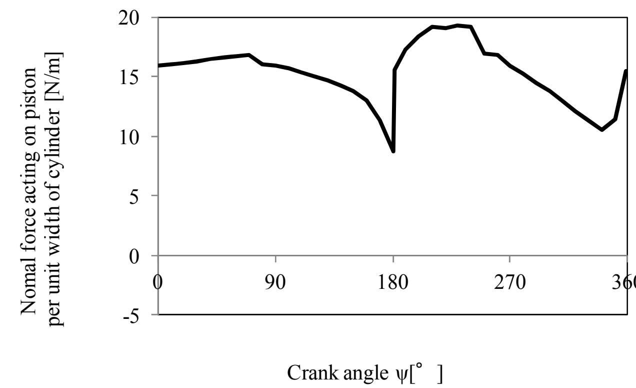
Oil film reactive force of vane sliding surface F_{o2}

Normal force acting on piston at vane contact





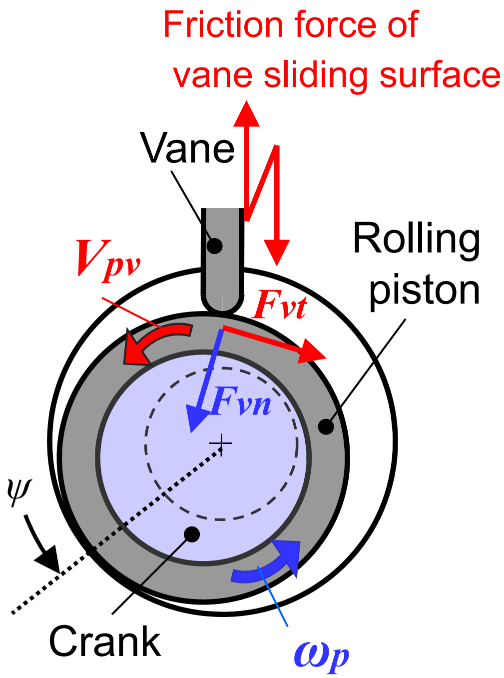
Contact friction force of vane sliding surface

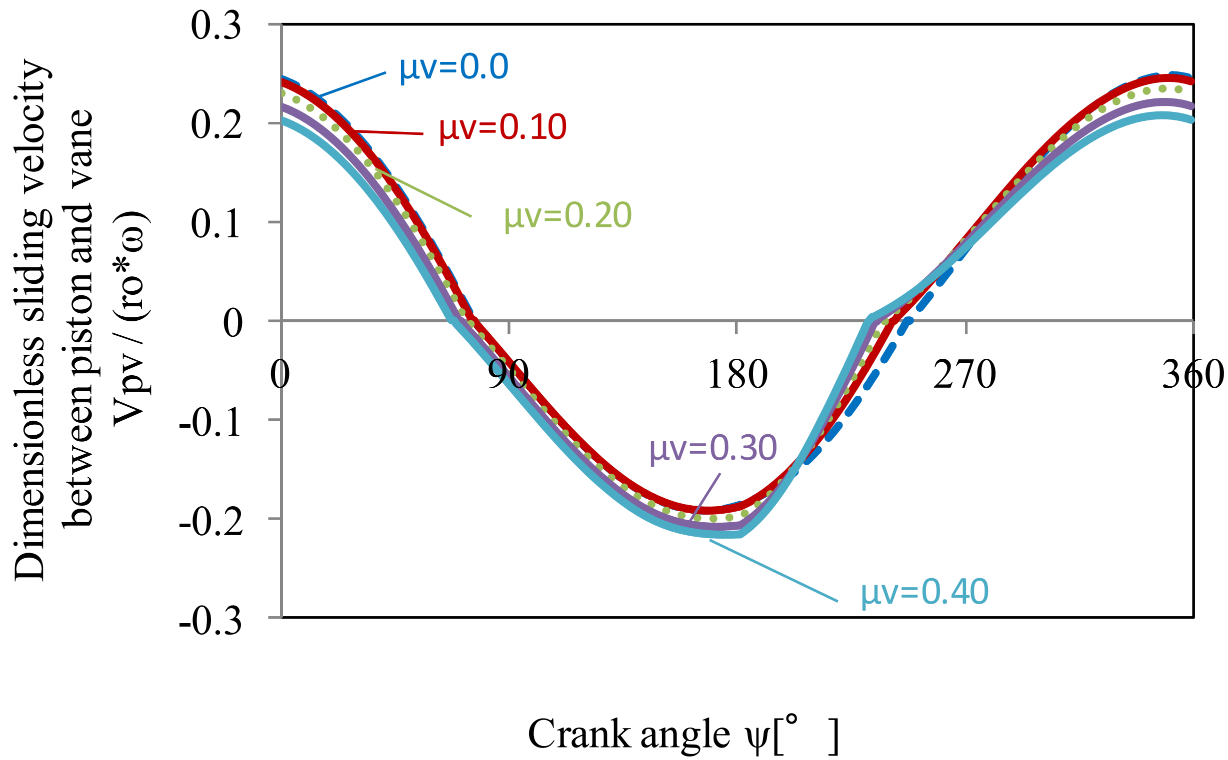


Normal force acting on piston at vane contact F_{vn}

- Contact friction force is negative at ψ = 180° .
- F_{vn} is minimized at ψ = 180° .

Effect of friction coefficient of vane sliding surface on relative sliding velocity between piston and vane *Vpv*

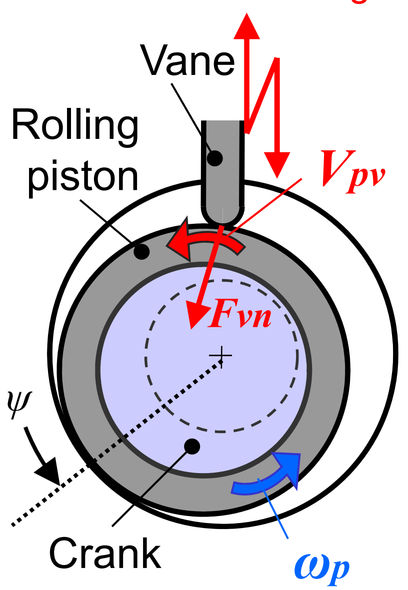




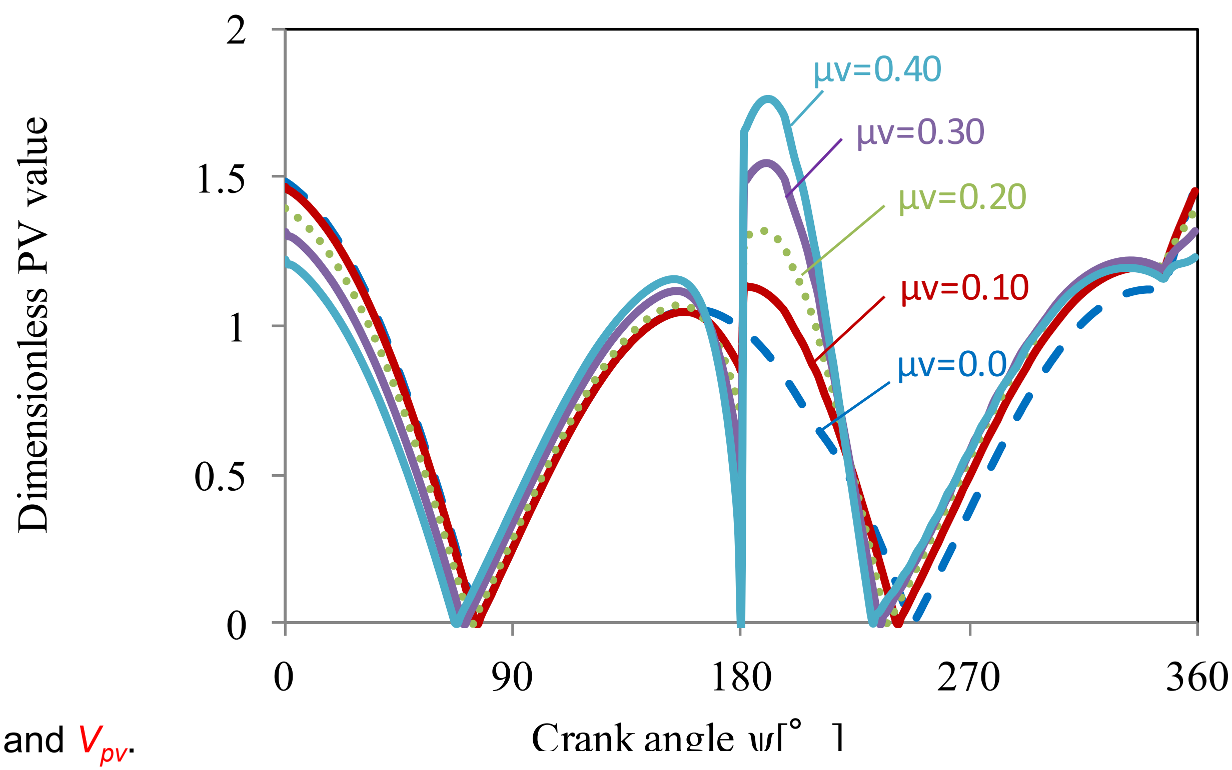
Variation of relative sliding velocity: ***Vpv***

- *Vpv* decrease for all crank angles.
- This is because F_{vt} increases when *μv* increases.

Effect of friction coefficient of vane sliding surface on PV value between piston and vane



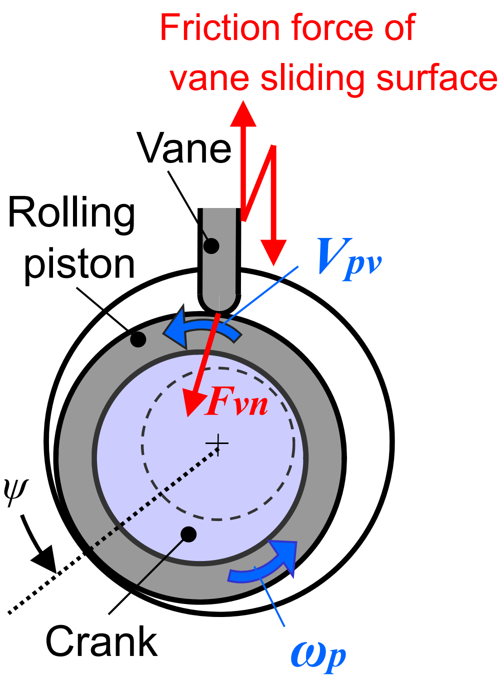
PV value is calculated from F_{vn} and V_{pv}.

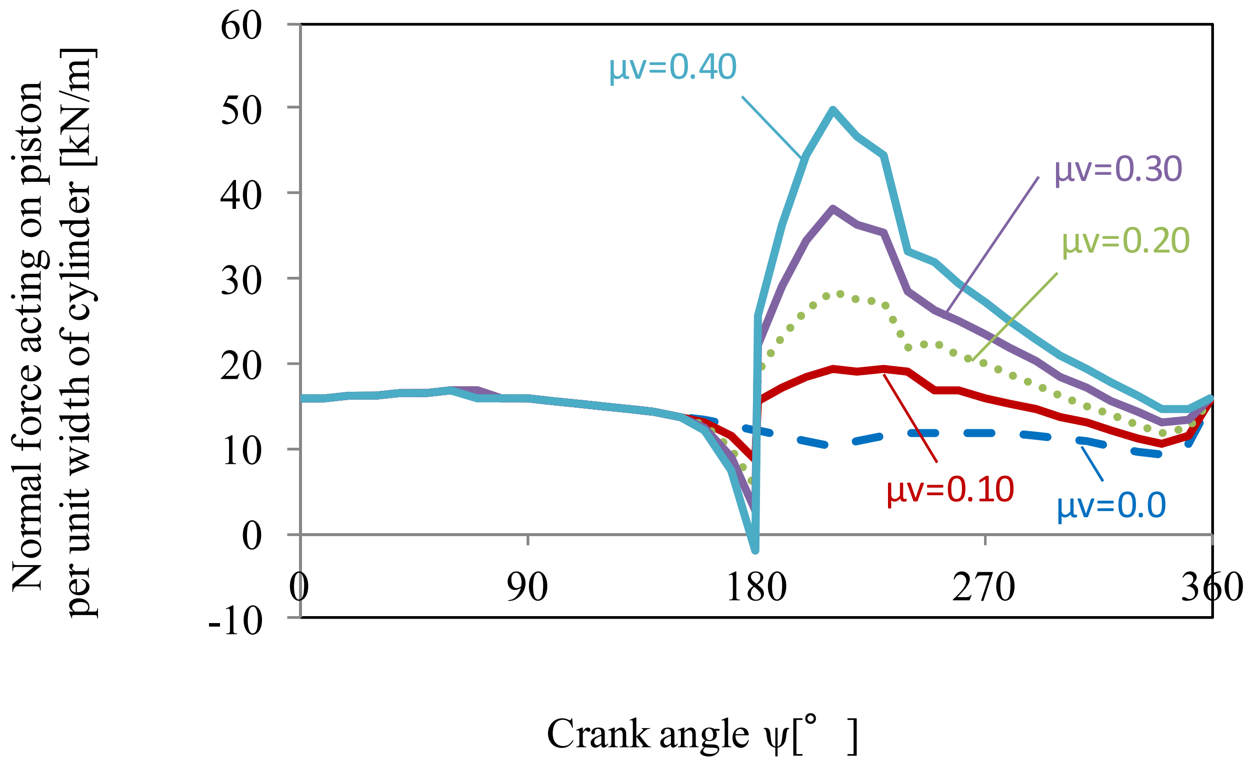


Variation of PV value

- *PV value* near ψ=180° increase.
- Risk of scuffing decreases when *μv* decreases

Effect of friction coefficient of vane sliding surface on normal force acting on piston at vane contact *Fvn*

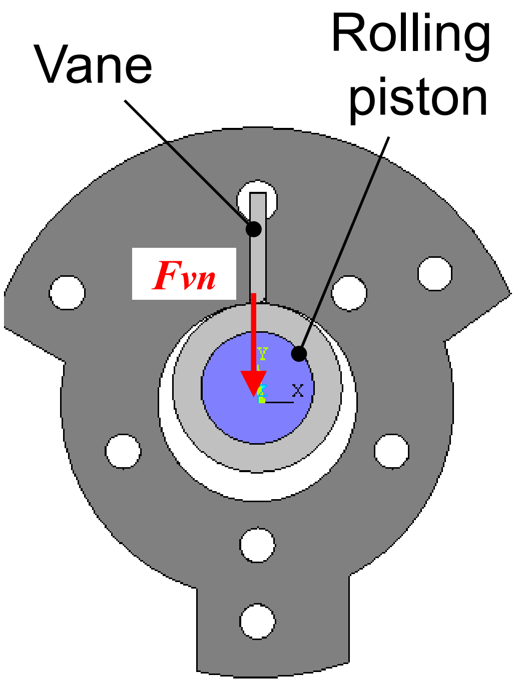


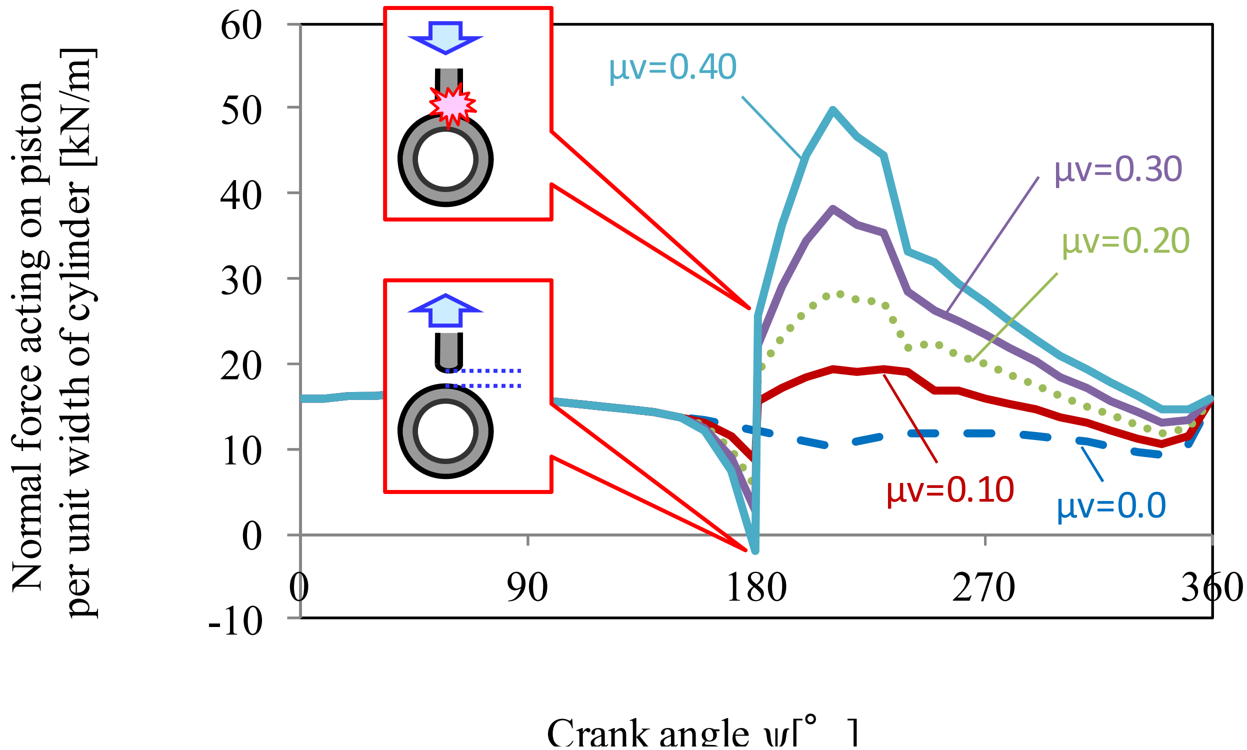


Variation of normal force acting on piston at vane contact ***Fvn***

- F_{vn} becomes negative near ψ=180° when μ_v increases.

Effect of friction coefficient of vane sliding surface on normal force acting on piston at vane contact *Fvn*





Variation of normal force acting on piston at vane contact ***Fvn***

・Vane collides with piston and an excessive impact occurs.
・Analysis results reveal the necessity of decreasing the friction force of vane sliding surface to prevent separation of the vane and the piston.

Conclusion

The numerical analysis of the motion of the rolling piston and the motion of the vane considering mixed lubrication of the vane sliding surface has been performed to investigate the influences of the contact friction of the vane sliding surface on the lubricating condition between the vane top and rolling piston.

- **The risk of scuffing is high between the vane top and piston because of increased PV value near crank angle $\psi=180^\circ$, at which the lubricating condition is severe when the contact friction forces of the vane sliding surface increases.**
- **The vane separated from the piston collides with the piston and an excessive impact occurs between the vane top and the piston because of the increased the contact friction forces of the vane sliding surface. Thus, the risk of surface damage at the vane top becomes high.**
- **Consequently, to maintain good vane top surface condition, it is important to guarantee and to maintain the sufficient lubrication of the vane sliding surface.**