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A Geometrical Model of Piston-Liner System

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Abstract: *A numerical model for the skirt is studied to consider the effects of the connecting rod inertia on the piston skirt–liner system lubrication. The piston motion, the oil film lubrication model and the friction losses of the system have been studied and compared. The results on a dual cylinder diesel engine show that inertia of connecting rod also affects system lubrication as well as the piston motion, especially at higher speeds.*

Keywords: *Piston secondary motion, liner system*

Nomenclature

BTDC-Before Top Dead Center
F_t-Side Thrust Force
T.S.-Thrust Side
A.T.S.-Anti Thrust Side
F_h-Hydo dynamic oil force
T_G-Gas Torque
T_f-Frictional torque around pin
F_{icr}-Connecting rod inertial force
h-Oil film thickness
η-Oil Viscosity
Fs-Side thrust force
m_R-Mass of connecting rod
m_p-Mass of pin
m_{piston} -Mass of piston
u-Piston Velocity

1. Introduction

Piston Skirt –liner system contributes a major amount in combustion engines [1]. Simulation of lubrication between skirt and liner is needed from tribological system of engine. Li et al was first to consider plot of piston motion versus crank angle [5].Skirt surface roughness effects were later considered by Wong et al[6].Later piston design parameters were considered [7]. Inertial forces were never considered which can never be neglected typically at high speeds. In present work these effects have been considered for lubrication mode.

2. Numerical model

Motion of piston may be expressed as:

$$\begin{bmatrix} m_{pin}\left(1-\frac{b}{L}\right)+m_{pis}\left(1-\frac{a}{L}\right) & m_{pin}\left(\frac{b}{L}\right)+m_{pis}\left(1-\frac{a}{L}\right) \\ m_{pis}\left(1-\frac{a}{L}\right)(b-a)+\left(\frac{J_{pis}}{L}\right) & m_{pis}\left(\frac{a}{L}\right)(b-a)-\left(\frac{J_{pis}}{L}\right) \end{bmatrix}\begin{bmatrix} e''_t \\ e''_b \end{bmatrix}$$
$$= \begin{bmatrix} F_S + F_{SK}\,Tan\,\phi + S \\ M_S + M_{fSK} + M \end{bmatrix} \quad (1)$$

Various forces and moments can be expressed in form:

$$Fs = (F_g+m_pg+Y_p''m_p)Tan\phi \quad (2)$$

$$Ms = (F_g Cg - m_{piston}\, g\, Cp - Y_p'' m_p) \tag{3}$$

Taking into account inertial forces the new system of equations can be written as:

$$F_{ic} + F_{BX} + S + F_{ip} \quad = \quad 0 \tag{4}$$

$$F_g Cg + M_{pis} + M + M_{fSK} + (\bar{F}_{ic} - m_p g)Cg + F_{ic}(C_B - C_A) = 0 \tag{5}$$

Where

$$F_{ic} = -m_{\,pis}\left(e_t'' - \left(\frac{a}{L}\right)(e_t'' - e_b'')\right) \tag{6}$$

$$F_{ip} = -m_{\,pis}\left(e_t'' - \left(\frac{a}{L}\right)(e_t'' - e_b'')\right) \tag{7}$$

$$\bar{F}_{ic} = -m_{\,pis}\, Y_p'' \tag{8}$$

$$\bar{F}_{ip} = -m_{\,pin}\, Y_p'' \tag{9}$$

For connecting rod various forces may be expressed as:

$$F_{BX} = (F_{BY} + j\, Y_p''\, m_R + jgm_R)\mathrm{tg}\phi - j\, X_p''\, m_R - \frac{\ddot{\phi}\, I_R}{L\cos\phi} \tag{10}$$

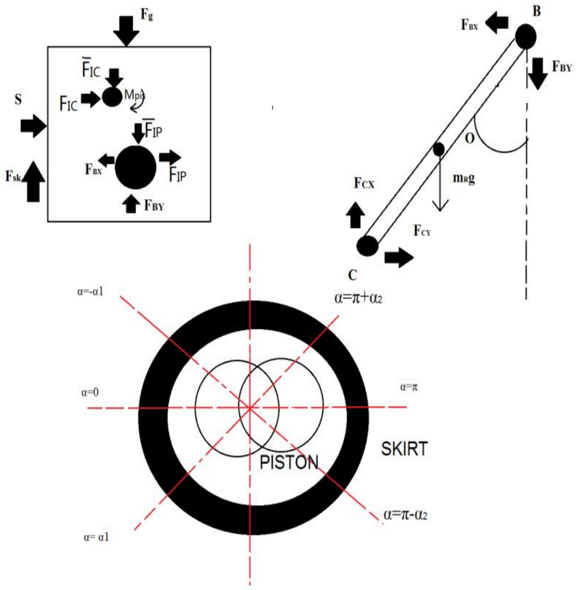

Fig. 1. Force equilibrium

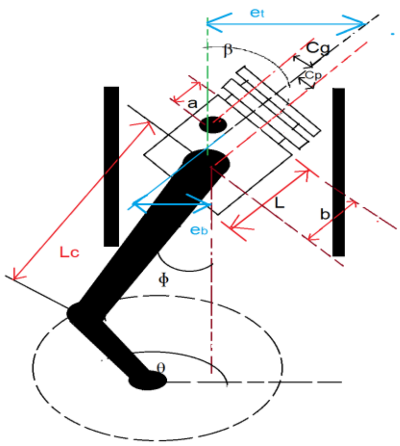

Fig. 2. Piston Motion

Hence piston dynamics equations can be written as:

$$\begin{bmatrix} m_{pin}\left(1-\frac{b}{L}\right)+m_{pis}\left(1-\frac{a}{L}\right)+j^2m_R\left(1-\frac{b}{L}\right) & m_{pin}\left(\frac{b}{L}\right)+m_{pis}\left(\frac{a}{L}\right)+j^2m_R\left(\frac{b}{L}\right) \\ m_{pis}\left(1-\frac{a}{L}\right)(b-a)+\left(\frac{J_{pis}}{L}\right) & m_{pis}\left(\frac{a}{L}\right)(b-a)-\left(\frac{J_{pis}}{L}\right) \end{bmatrix}\begin{bmatrix}(e_t{''} \\ (e_b{''}\end{bmatrix}$$

$$=\begin{bmatrix}F'_S+F_{SK}\,Tan\,\phi+S \\ M_S+M_{fSK}+M\end{bmatrix} \quad (11)$$

$$F'_s=(F_g+m_pg+Y_p''m_p+jm_RY_R''+jgm_R)\mathrm{Tan}\phi-\frac{\phi'' I_R}{Lcos\phi}-J\mathrm{Sin}\theta\Theta''^2 \mathrm{r}(1-\mathrm{j})m_R \quad (12)$$

Connecting rod inertial force may be written as:

$$F_{icr}=(jm_RY_R''+jgm_R)\mathrm{Tan}\phi-\frac{\phi'' I_R}{Lcos\phi}-J\mathrm{Sin}\theta\Theta''^2 \mathrm{r}(1-\mathrm{j})m_R \quad (13)$$

3. Hydro dynamic lubrication

Reynolds equation can be used to calculate the lubrication oil pressure between skirt and liner as:

$$\frac{\delta}{\delta x}\left(\frac{\rho h^3\phi_x}{12\eta}\frac{\delta P}{\delta x}\right)+\frac{\delta}{\delta y}\left(\frac{\rho h^3\phi_y}{12\eta}\frac{\delta P}{\delta y}\right)=\rho\frac{\delta h}{\delta t}\phi_c-\frac{u}{2}\left(\frac{\delta h}{\delta y}\phi_c\rho+\sigma\frac{\delta(\rho\phi_s)}{\delta y}\right) \quad (14)$$

The average shear stress on skirt can be expressed in terms of shear stress factors ϕ_f, ϕ_{fs} as :

$$\tau=-\eta\frac{u}{h}(\phi_f+\phi_{fs})-\phi_{fP}\frac{\delta P}{\delta y}\frac{h}{2} \quad (15)$$

Various forces and moments can be expressed as

$$S=R\iint[(p+pc)cos\alpha d\alpha dy] \quad (16)$$

$$M=R\iint[(p+pc)cos\alpha d\alpha dy(y-b)] \quad (17)$$

$$F_{SK}=R\iint[\tau d\alpha dy] \quad (18)$$

$$M_{fSK}=R\iint[\tau d\alpha dy(Rcos\alpha-Cp)] \quad (19)$$

4. Results and discussions

Piston motion equations are stiff and non linear differential equations which were solved using time step Runger Kutta method using various engine parameters used are listed in table no 1.

TABLE 1: Engine Parameters

Parameter	Value
a	31.3250 mm
b	36.9mm
C	0.05mm
Cg	0mm
Cp	0mm
J_{piston}	6.6200X 10^{-07} Kg-m^2
R	30.3mm
I_{rod}	7.8540X10^{-09}Kg-m^2
r	34mm

TABLE 1: Engine Parameters *(continued)*

Parameter	**Value**
j	0.12
L	62.65mm
m_R	200 g
m_{pin}	81g
m_{piston}	363 g
η	0.03 Pa-S
L_c	121mm

Figure no 3 shows plots of side thrust forces. Values of side thrust forces increases while taking into consideration connecting rod inertia. Figure no 3 shows the plots of lubrication oil pressure with as well as without taking into consideration connecting rod inertia. Both plots show same trend, however peak value of pressure taking into account inertia force (Figure 3,b) is lesser than normal oil pressure (Figure 3,a).

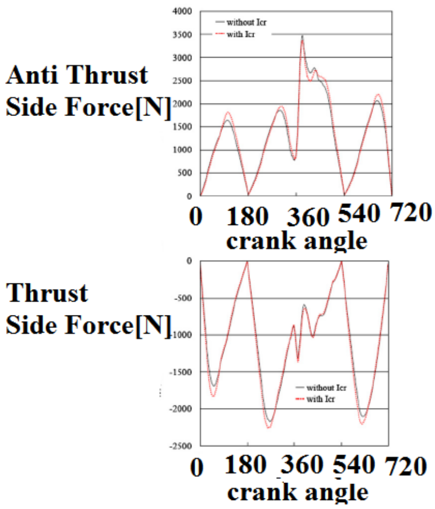

Fig. 3. Schematic representation of side force [24]

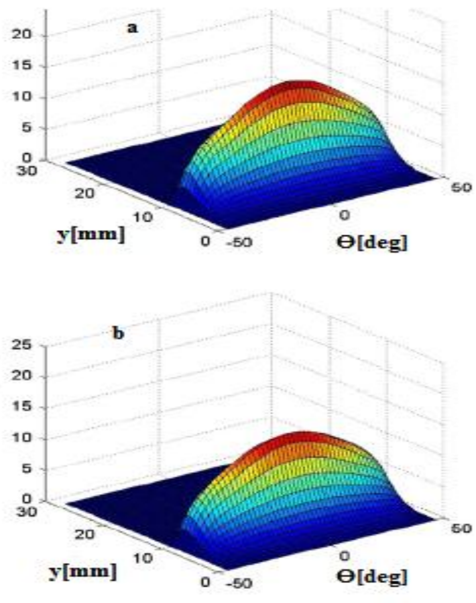

Fig. 4. Oil pressure distribution [24]

Figure no 4 shows top eccentricity of piston (e_t) calculated by solving piston dynamics equations considering various forces and moments. It can be seen that piston displacement increases while taking into connecting rod inertial forces after TDC position. Figure no 8 shows plots of oil film thickness as a function of crank angle. It can be seen that oil film thickness is thick enough and engine runs at full film lubrication. Oil film thickness is greater while taking into account connecting rod inertial force.

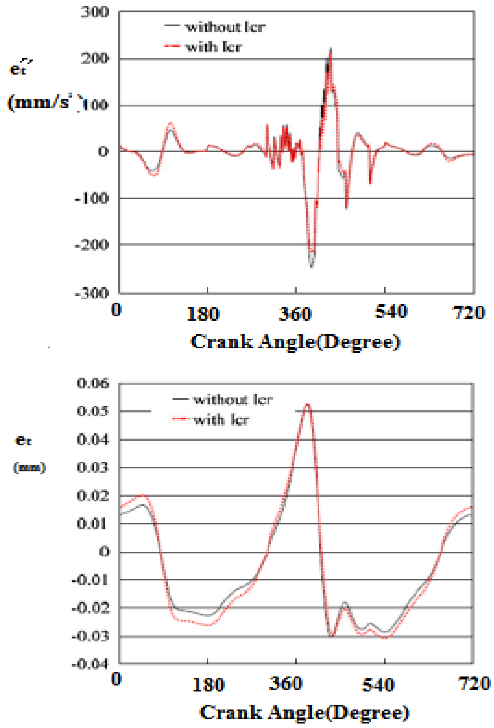

Fig. 5. Piston motion [24]

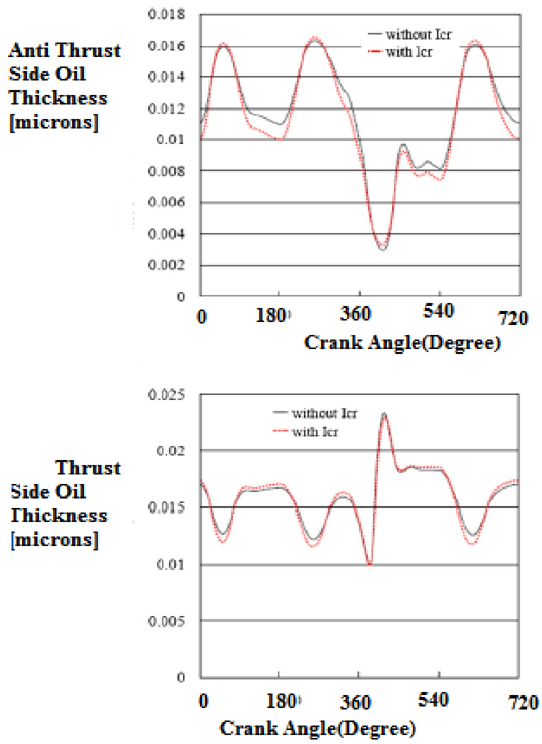

Fig. 6. Oil film thickness [24]

5. Conclusions

This work considers the effects of connecting rod inertial force on various parameters of piston-liner model. This force increases with speed. Side thrust forces as well as piston secondary motion increases while taking into account inertial forces.

References

[1] S.C. Tung, M.L. McMillan, "Automotive tribology overview of current advances and challenges for the future", In: Tribology International, 2004; 37:517–35;
[2] D.F. Li, S.M. Rhode, H.A. Ezzat, "An automotive piston lubrication model", ASLE Transactions 1983;26(2):151–60;
[3] V.W. Wong, T. Tian, H. Lang, J.P. Ryan, Y. Sekiya, Y. Kobayashi, *et al.*, "A numerical model of piston secondary motion and piston slap in partially flooded elasto hydrodynamic skirt lubrication", SAE paper no. 940696, 1994;
[4] S. Jiang, J. Cho, "Effects of skirt profiles on the piston secondary movements by the lubrication behaviors", In: International Journal of Automotive Technology 2004;5(1):23–31;
[5] A. Gupta, S. Narayan, "Electrical Analogy of Liquid Piston Stirling Engines", In: Hidraulica no. 2 (2016): 58;
[6] S. Narayan, V. Gupta, "Overview of working of Striling engines", In: Journal of Engineering Studies and Research, 21.4 (2015): 45;
[7] A. Gupta, S. Narayan, "A Review of Heat Engines", In: Hidraulica no. 1 (2016): 67;
[8] S. Narayan, "Analysis of noise emitted from diesel engines", In: Journal of Physics: Conference Series. Vol. 662. no. 1. IOP Publishing, 2015;
[9] A. Gupta, S. Narayan. "Effects of turbo charging of spark ignition engines", In: Hidraulica no. 4 (2015): 62;
[10] S. Narayan, "Designing of liquid piston fluidyne engines", In: Hidraulica no. 2 (2015): 18;
[11] S. Narayan, "Effects of Various Parameters on Piston Secondary Motion", No. 2015-01-0079. SAE Technical Paper, 2015;
[12] S. Narayan, "Analysis of Noise Radiated from Common Rail Diesel Engine", In: Tehnički glasnik, 8.3 (2014): 210-213;
[13] S. Narayan, "Time-frequency analysis of Diesel engine noise", In: Acta Technica Corviniensis-Bulletin of Engineering, 7.3 (2014): 133.
[14] S. Narayan, "Wavelet Analysis of Diesel Engine Noise", In: Journal of Engineering and Applied Sciences, 8.8 (2013): 255-259;
[15] S. Narayan, V. Gupta. "Motion analysis of liquid piston engines", In: Journal of Engineering Studies and Research, 21.2 (2015): 71;
[16] S. Narayan, "Modeling of Noise Radiated from Engines", No. 2015-01-0107. SAE Technical Paper, 2015;
[17] S. Narayan, A. Gupta, R. Rana, "Performance analysis of liquid piston fluidyne systems", In: Mechanical Testing and Diagnosis, 5.2 (2015): 12;
[18] V. Gupta, S. Sharma, S. Narayan, "Review of working of Stirling engines", In: Acta Technica Corviniensis-Bulletin of Engineering, 9.1 (2016): 55;
[19] A. Singh, S. Bharadwaj, S. Narayan, "Review of how aero engines work", In: Tehnički glasnik, 9.4 (2015): 381-387;
[20] S. Narayan, "A review of diesel engine acoustics", In: FME Transactions, 42.2 (2014): 150-154;
[21] S. Narayan, "Noise Optimization in Diesel Engines", In: Journal of Engineering Science and Technology Review, 7.1 (2014): 37-40;
[22] V. Gupta, S. Sharma, S. Narayan. "Review of working of Stirling engines", In: Acta Technica Corviniensis-Bulletin of Engineering, 9.1 (2016): 55;
[23] A. Singh, S. Bharadwaj, S. Narayan, "Prikaz rada motora zrakoplova", In: Tehnički glasnik, 9.4 (2015): 381-387;
[24] X. Meng, Y. Xie, "A new numerical analysis for piston skirt–liner system lubrication considering the effects of connecting rod inertia", In: Tribology International, 47 (2012): 235-243.