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Analysis of the Pressure Distribution for Press Shoe considering Partially Changed Curvature of Bearing Surface

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Abstract: A press shoe is an element of a machine for squeezing water from wood pulp in the field of manufacturing paper. This is used to compress the pulp enveloped by felt sheet with a large roller. The squeezing force is made by hydraulic pressure. The press shoe has a mechanism similar to a partial hydrostatic bearing. The pressure profile between press shoe and roller affects their squeezing ability, and partial peak pressure can tear the wet pulp. The curvature of the surface of press shoe varies to reduce the peak pressure and increase the mean pressure simultaneously. Therefore, the prediction of pressure distribution considering partially changed curvature of hydrostatic bearing is very important for designing the press shoe. In this study, the difference formulation of Reynolds equation for partial hydrostatic bearing is derived by direct numerical method and a computer program to calculate the pressure distribution is developed. We investigate the effect of partially changed curvature of bearing surface on the pressure distribution. Other design parameter for hydrostatic bearing such as depth of pocket and relative velocity are also studied.

Keywords: Press shoe partially changed curvature, hydrostatic bearing, direct numerical method

Introduction

In recent years, shoe presses, composed of roller and hydrostatic bearing, have been used to wring out wet paper. The squeezing ability of these machines depends highly upon their pressure profile between roller and bearing because the amount of remained water can be predicted by the pressure profile. At shoe press, the pressure is formed by tilting two pads, which make higher average pressure. But these mechanisms have some defect that has sudden rising pressure at the end part of bearing (see Fig. 2, tilting 1). This kind of peak pressure may cut off the paper. If we can reduce sudden rising pressure (see Fig. 2, tilting 2), these machines operate at a higher average pressure and have more efficiency. Therefore, the calculation of pressure profile in the shoe press is very important in order to design shoe press.

For these goals, we develop a computer program, which can calculate the pressure profile at the press shoe. This program can consider the curvature of bearing surface. We study the pressure profile according to variable pocket height and variable front or rear land shape. We know that land shape plays an import role in making pressure profile.

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Governing Equation

Governing Equation
If the lubricant fluid isnt generated and disappeared by itself in steady state, continuity equation is

$$\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z} = 0$$

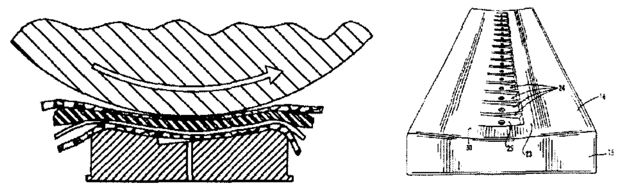


Fig. 1. An object of study.

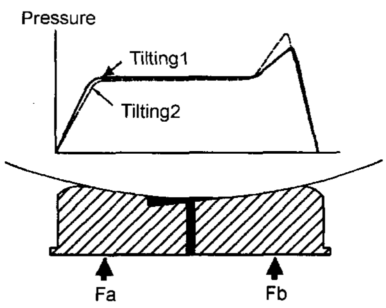


Fig. 2. Pressure distribution of object.

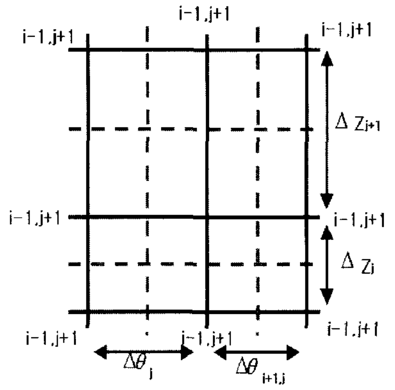


Fig. 3. Mesh for analysis.

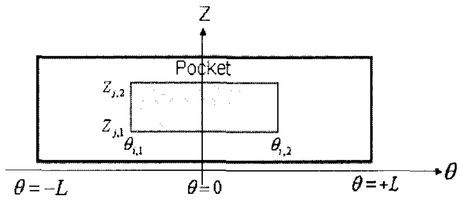


Fig. 4. Flux to flow out pocket.

The Navier-Stokes Equation for incompressible fluid make simple by the follows supposing,

⊙ Supposing to simplicity

1) Due to h is smaller than diameter D, or width Z, h is neglected.
2) Pressure gradient in the x-direction is zero
3) Flow is laminar flow.
4) There is no external force to act on fluid.
5) Centrifugal force and initial force is neglected.
6) There is no slip in the roller surface.
7) Other velocity gradient except $\frac{\partial u}{\partial y}, \frac{\partial w}{\partial y}$ is smaller, so may be neglected.

And the equation is integrated by film thinness h, mass flux is

$$q_x = -\frac{h^3}{12\mu}\frac{\partial p}{\partial x} + \frac{h}{2}U$$

$$q_z = -\frac{h^3}{12\mu}\frac{\partial p}{\partial x}$$

Flux to flow out pocket

The mass flux is descretized by the following dimensionless parameter.

$$Q = \frac{12\mu}{PaC^3}q$$

The dimensionless flux from pocket is defined as

$$Q_{out} = Q_{ax} + Q_E - Q_W$$

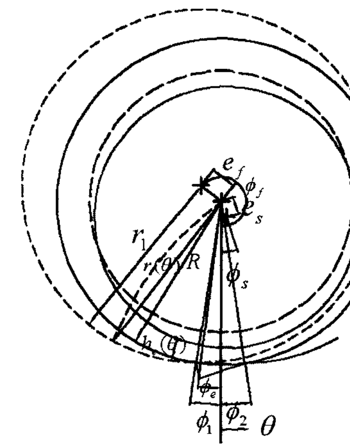


Fig. 5. The lubricant film thickness.

where

$$Q_{ax} = \int_{\theta_{i,1}}^{\theta_{i,2}}\left[\frac{(P_r - P)}{dZ}H^3\right]_{Z = Z_{i,2}} d\theta + \int_{\theta_{i,1}}^{\theta_{i,2}}\left[\frac{(P - P_r)}{dZ}H^3\right]_{Z = Z_{j,1}} d\theta$$

$$Q_E = \int_{Z_{j,1}}^{Z_{j,2}}\left[-\frac{(P_r - P)}{d\theta}H^3 + \Lambda H\right]_{\theta = \theta_{i,2}} dZ$$

$$Q_W = \int_{Z_{j,1}}^{Z_{j,2}}\left[-\frac{(P_r - P)}{d\theta}H^3 + \Lambda H\right]_{\theta = \theta_{i,1}} dZ$$

Q_{ax} : The flux to go out of pocket
Q_E : The flux to flow through pocket from left side to right side
Q_W : The flux to flow through pocket from right side to left side

Flux to flow in through orifice

The dimensionless flux to flow in through orifice is defined as

$$Q_{in} = \frac{12\mu}{\sqrt{P_a}C^3}K_B\sqrt{P_s - P_r}$$

where,

$$K_B = \left(\sqrt{\frac{\rho}{2}}\left[\frac{1}{\alpha A_i} - \frac{1}{A_0}\right]\right)^{-1}$$

$$\alpha = 0.63 + 0.37\left(\frac{A_i}{A_o}\right)^6$$

Lubricant film thickness

The dimensionless film thickness is written as

$$H(\theta) = \frac{1}{C}[r(\theta) + h_e(\theta) - R]$$

where,

if ($\theta < -\phi_1$ and $0 < Z$)
$r(\theta) = e_f\cos(\phi_f - \theta)$

$$+\sqrt{e_f^2\cos^2(\phi_f-\theta)-e_f^2+r_1^2}$$

$$h_e(\theta)=C-e_s(\theta-\phi_s)$$

if ($-\phi_1<\theta<\phi_e$ and Z is in the pocket)

$$r(\theta)=-\frac{R\sin\phi_1}{\sin\theta}$$

$$h_e(\theta)=C-e_s(\theta-\phi_s)$$

if ($-\phi_e<\theta<\phi_2$ and Z is in the pocket)

$$r(\theta)=-\frac{\tan(\pi/2+\beta)(R\cos\phi_1+a+1)\left(\frac{\sin\phi_2}{\sin\phi_1+\sin\phi_2}\right)}{\sin\theta-\tan(\pi/2+\beta)\cos\theta}$$

$$h_e(\theta)=C-e_s(\theta-\phi_s)$$

if ($-\phi_2<\theta$ and $0<Z$)

$$r(\theta)=e_r\cos(\phi_r-\theta)$$

$$+\sqrt{e_r^2\cos^2(\phi_r-\theta)-e_r^2+r_2^2}$$

$$h_e(\theta)=C-e_s(\theta-\phi_s)$$

Numerical Approximation Method

Finite Difference Equation

At nozzle, the Reynolds equation is expressed as follows.

$$\left[H^3\frac{\partial P}{\partial\theta}-\Lambda H\right]_{i+\frac{1}{2},j}\cdot\Delta Z-\left[H^3\frac{\partial P}{\partial\theta}-\Lambda H\right]_{i-\frac{1}{2},j}\cdot\Delta Z$$
$$+\left[H^3\frac{\partial P}{\partial\theta}\right]_{i,j+\frac{1}{2}}\cdot\Delta\theta-\left[H^3\frac{\partial P}{\partial\theta}\right]_{i,j-\frac{1}{2}}\cdot\Delta\theta=0$$

This equation is simplified as follows:

$$A_pP_{i,j}=A_EP_{i+1,j}+A_WP_{i-1,j}+A_SP_{i,j-1}+A_NP_{i,j+1}$$
$$+A_{EN}P_{i+1,j+1}+A_{ES}P_{i+1,j-1}+A_{WN}P_{i-1,j+1}$$
$$+A_{WS}P_{i-1,j-1}+A_{tot}$$

At other points, the Reynolds equation is expressed as

$$\left[H^3\frac{\partial P}{\partial\theta}-\Lambda H\right]_{i+\frac{1}{2},j}\cdot\Delta Z-\left[H^3\frac{\partial P}{\partial\theta}-\Lambda H\right]_{i-\frac{1}{2},j}\cdot\Delta Z$$
$$+\left[H^3\frac{\partial P}{\partial\theta}\right]_{i,j+\frac{1}{2}}\cdot\Delta\theta-\left[H^3\frac{\partial P}{\partial\theta}\right]_{i,j-\frac{1}{2}}\cdot\Delta\theta$$
$$+\frac{12\mu}{\sqrt{P_a}C^3}K_B\sqrt{P_s-P_r}=0$$

This equation is simplified as follows:
where,

$$A_pP_{i,j}=A_EP_{i+1,j}+A_WP_{i-1,j}+A_SP_{i,j-1}+A_NP_{i,j+1}$$
$$+A_{EN}P_{i+1,j+1}+A_{ES}P_{i+1,j-1}+A_{WN}P_{i-1,j+1}$$
$$+A_{WS}P_{i-1,j-1}+A_{tot}+\frac{12\mu}{\sqrt{P_a}C^3}K_B\sqrt{P_s-P_r}$$

$$A_P=\frac{3}{8}^*H^3_{i+1/2,j+1/4}{}^*\frac{\Delta Z_{j+1}}{\Delta\theta_{i+1}}+\frac{3}{8}^*H^3_{i+1/2,j-1/4}{}^*\frac{\Delta Z_j}{\Delta\theta_{i+1}}$$
$$+\frac{3}{8}^*H^3_{i-1/2,j+1/4}{}^*\frac{\Delta Z_{j+1}}{\Delta\theta_i}+\frac{3}{8}^*H^3_{i-1/2,j-1/4}{}^*\frac{\Delta Z_j}{\Delta\theta_i}$$
$$+\frac{3}{8}^*H^3_{i+1/4,j+1/2}{}^*\frac{\Delta Z_{i+1}}{\Delta\theta_{j+1}}+\frac{3}{8}^*H^3_{i-1/4,j+1/2}{}^*\frac{\Delta\theta_j}{\Delta Z_{j+1}}$$
$$+\frac{3}{8}^*H^3_{i+1/4,j-1/2}{}^*\frac{\Delta\theta_{i+1}}{\Delta Z}+\frac{3}{8}^*H^3_{i-1/4,j-1/2}{}^*\frac{\Delta\theta_i}{\Delta Z_j}$$

$$A_E=\frac{3}{8}^*H^3_{i+1/2,j+1/4}{}^*\frac{\Delta Z_{j+1}}{\Delta\theta_{i+1}}+\frac{3}{8}^*H^3_{i+1/2,j-1/4}{}^*\frac{\Delta Z_j}{\Delta\theta_{i+1}}$$
$$-\frac{1}{8}^*H^3_{i+1/4,j+1/2}{}^*\frac{\Delta\theta_{i+1}}{\Delta Z_{j+1}}-\frac{1}{8}^*H^3_{i+1/4,j-1/2}{}^*\frac{\Delta\theta_{i+1}}{\Delta Z_j}$$

$$A_W=\frac{3}{8}^*H^3_{i-1/2,j+1/4}{}^*\frac{\Delta Z_{j+1}}{\Delta\theta_i}+\frac{3}{8}^*H^3_{i-1/2,j-1/4}{}^*\frac{\Delta Z_j}{\Delta\theta_i}$$
$$-\frac{1}{8}^*H^3_{i-1/4,j+1/2}{}^*\frac{\Delta\theta_i}{\Delta Z_{j+1}}-\frac{1}{8}^*H^3_{i-1/4,j-1/2}{}^*\frac{\Delta\theta_i}{\Delta Z_j}$$

$$A_S=-\frac{1}{8}^*H^3_{i+1/2,j-1/4}{}^*\frac{\Delta Z_j}{\Delta\theta_{i+1}}-\frac{1}{8}^*H^3_{i-1/2,j-1/4}{}^*\frac{\Delta Z_j}{\Delta\theta_i}$$
$$+\frac{3}{8}^*H^3_{i+1/4,j-1/2}{}^*\frac{\Delta\theta_{i+1}}{\Delta Z_j}+\frac{3}{8}^*H^3_{i-1/4,j-1/2}{}^*\frac{\Delta\theta_i}{\Delta Z_j}$$

$$A_N=-\frac{1}{8}^*H^3_{i+1/2,j+1/4}{}^*\frac{\Delta Z_{j+1}}{\Delta\theta_{i+1}}-\frac{1}{8}^*H^3_{i-1/2,j+1/4}{}^*\frac{\Delta Z_{j+1}}{\Delta\theta_i}$$
$$+\frac{3}{8}^*H^3_{i+1/4,j+1/2}{}^*\frac{\Delta\theta_{i+1}}{\Delta Z_{j+1}}+\frac{3}{8}^*H^3_{i-1/4,j+1/2}{}^*\frac{\Delta\theta_i}{\Delta Z_{j+1}}$$

$$A_{WN}=\frac{1}{8}^*H^3_{i+1/2,j+1/4}{}^*\frac{\Delta Z_{j+1}}{\Delta\theta_{i+1}}+\frac{1}{8}^*H^3_{i+1/4,j+1/2}{}^*\frac{\Delta\theta_{i+1}}{\Delta Z_{j+1}}$$

$$A_{ES}=\frac{1}{8}^*H^3_{i+1/2,j-1/4}{}^*\frac{\Delta Z_j}{\Delta\theta_{i+1}}+\frac{1}{8}^*H^3_{i+1/4,j-1/2}{}^*\frac{\Delta\theta_{i+1}}{\Delta Z}$$

$$A_{EN}=\frac{1}{8}^*H^3_{i-1/2,j+1/4}{}^*\frac{\Delta Z_{j+1}}{\Delta\theta_i}+\frac{1}{8}^*H^3_{i-1/4,j+1/2}{}^*\frac{\Delta\theta_i}{\Delta Z_{j+1}}$$

$$A_{WS}=\frac{1}{8}^*H^3_{i-1/2,j-1/4}{}^*\frac{\Delta Z_j}{\Delta\theta_i}+\frac{1}{8}^*H^3_{i-1/4,j-1/2}{}^*\frac{\Delta\theta_i}{\Delta Z_j}$$

$$A_{tot}=\Lambda^*(H^3_{i-1/2,j+1/4}-H^3_{i+1/2,j+1/4})^*\frac{\Delta Z_{j+1}}{2}$$
$$+\Lambda^*(H^3_{i-1/2,j-1/4}-H^3_{i+1/2,j-1/4})^*\frac{\Delta Z_j}{2}$$

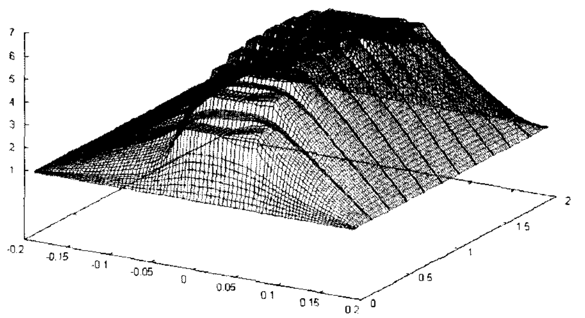


Fig. 6. Datum data.

Numerical procedure

If all pressure of pocket, eccentricity and attribute angle are given as input value, cost function is defined as follows:

$$F_1(P_{r1}, P_{r2}, \ldots, P_{r11}, \phi_s, e_s) = Q_{in,1} - Q_{out,1}$$

$$\cdots$$

$$F_{11}(P_{r1}, P_{r2}, \ldots, P_{r11}, \phi_s, e_s) = Q_{in,11} - Q_{out,11}$$

$$F_{12}(P_{r1}, P_{r2}, \ldots, P_{r11}, \phi_s, e_s) = F_{ext,x} - F_x$$

$$F_{13}(P_{r1}, P_{r2}, \ldots, P_{r11}, \phi_s, e_s) = F_{ext,y} - F_y$$

where, F_x, F_y are reaction force for x,y-direction which is made by pressure.

$$F_x = \int_{-\theta_L}^{\theta_L}\int_0^B (p - p_a)\sin\theta \; R \quad dz d\theta$$

$$F_y = \int_{-\theta_L}^{\theta_L}\int_0^B (p - p_a)\cos\theta \; R \quad dz d\theta$$

For solving previous formulations, We suppose pocket pressure, attitude angle to be input value, and $F_1 \ldots F_{13}$ to be cost function. And then, this equation is the follows.

$$X^{(n)} = X^{(n-1)} - J^{-1}X^{n-1}F(X^{n-1})$$

where,

$$= \begin{pmatrix} \frac{\partial F_1}{\partial P_{r1}} & \frac{\partial F_1}{\partial P_{r2}} & \frac{\partial F_1}{\partial P_{r3}} & \cdots & \frac{\partial F_1}{\partial P_{r11}} & \frac{\partial F_1}{\partial \phi_s} & \frac{\partial F_1}{\partial e_s} \\ & & & \cdots & & & \\ \frac{\partial F_{13}}{\partial P_{r1}} & \frac{\partial F_{13}}{\partial P_{r1}} & \frac{\partial F_{13}}{\partial P_{r1}} & \cdots & \frac{\partial F_{13}}{\partial P_{r1}} & \frac{\partial F_{13}}{\partial \phi_s} & \frac{\partial F_{13}}{\partial e_s} \end{pmatrix}$$

By Newton-Raphson method, all pressure of pocket, eccentricity and attribute angle to satisfy cost function is obtained.

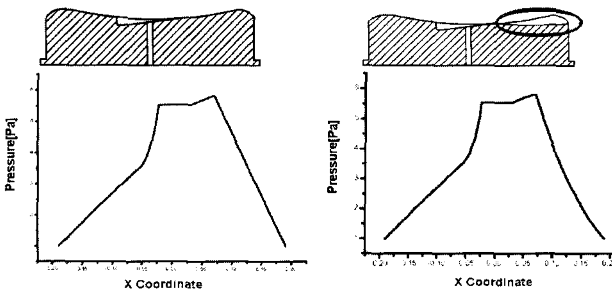
Result

In case of changing the land shape

Case1. Modified rear Land

If the curvature of rear land is modified and the pressure of nozzle at rear land to be modified is equal to that at normal rear land, maximum pressure has a tendency to **decrease**. Also, as clearance at land end is larger than that at pocket end, the peak pressure go down.

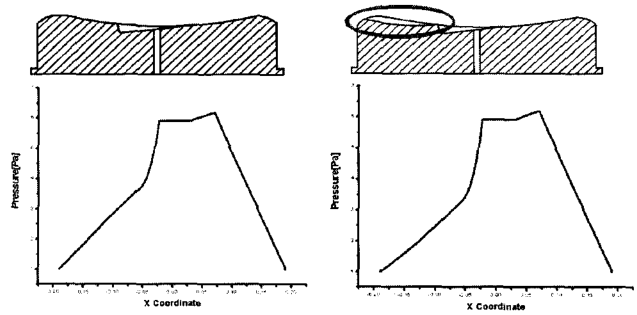
But the gradient of pressure at rear land is higher than that of normal rear land. As clearance at the end of rear land is the higher, average pressure at rear land becomes the smaller.



P_r =5.543409 P_{max} =5.813057 Difference=0.269648

P_r =5.543405 P_{max}=5.795923 Difference=0.252518

Fig. 7. Modified rear land.



P_r =5.91607 P_{max} =6.174515 Difference = 0.258445

P_r =5.91607 P_{max} =6.182475 Difference =0.266405

Fig. 8. Modified front land.

Case 2. Modified front Land

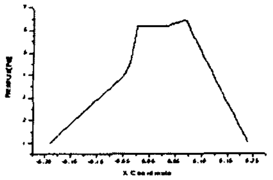
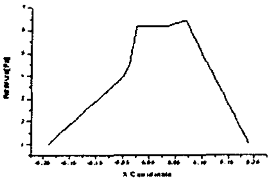
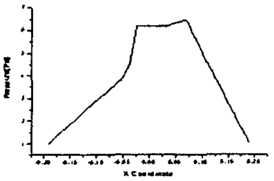
If the curvature of front land is modified and the pressure of nozzle at front land to be modified is equal to that at normal front land, maximum pressure has a tendency to **increase**.

Also, as clearance at land end is larger than that at pocket end, the peak pressure go up. And clearance at the end of front land is the higher, average pressure at front land becomes the higher.

The before-mentioned **result** shows the follows.

1. As the flux to enter the pocket is more, peak value increase.
2. As the flux to go out of the pocket is more, peak value decrease.

In the case of changing the pocket depth

	Pocket depth=10 mm P_r=6.137625 P_{max}=6.40211 Difference = 0.264485
	Pocket depth=15 mm P_r=6.137724 P_{max}=6.402237 Difference = 0.264513
	Pocket depth=20 mm P_r=6.137835 P_{max}=6.402376 Difference = 0.264541

In proportion to increasing the pocket depth, pressure is increased. But this increase rate is smaller than that of changing pocket curvature.

Conclution

The pressure to be performed at shoe press is influenced by angular velocity of roller, radius of roller, supply pressure, orifice diameter, and so on. By this study, we investigate the effect of partially changed curvature of bearing surface on the pressure distribution. It shows that the curvature of land influence fluid motion. By controlling the fluid to go out the pocket easily, the peak pressure is reduced.

References

1. Bernard J. Hamrock, "Fundamentals of Fluid Film Lubrication, McGraw-Hill, Inc, pp. 156-160, 1994.
2. Munho Yang, "A Study on the Improvement the Dynamic Characteristics of Hydrodynamic Journal Bearing", Ms. Thesis, Seoul National Univ., 1997 (in Korean).
3. Kyungsuk Jun, "A Study on the Characteristics of the Externally-Pressurized Gas Bearing", Ms. thesis, Seoul National Univ., 1990 (in Korean).
4. I.G.Currie, "Fundamental Mechanics of Flude", McGraw-Hill, Inc, second edition.
5. Pinkus and Sternlicht, "The Theory of Hydrodynamic Lubrication", McGraw-Hill, Inc, 1961.