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DEVELOPING A COMPUTATIONAL MODEL OF AXIAL OIL FLOW FROM A POROUS ROUGH HOLE

Prin. Dr. Pragna A. Vadher[1], Dr. Sanjeev Kumar[2],
Dr. Gunamani B. Deheri[3] & Rakesh M. Patel[4]

[1]*Principal, Government Science College, Idar, Gujarat, India.*

[2]*Professor & Head, Department of Mathematics, DBOU, Agra University, Agra, Uttar Pradesh, India.*

[3]*Associate Professor (Retired), Department of Mathematics, Sardar Patel University, Vallabh Vidyanagar, Gujarat, India.*

[4]*Department of Mathematics, Gujarat Arts & Science College, Ahmedabad, Gujarat, India.*

Corresponding author: E-mail: rmpatel2711@gmail.com

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Abstract

This study aims to present a new computational model for assessing how surface longitudinal roughness affects axial flow emerging from a hole. Christensen and Tonder's stochastic averaging model have been employed to develop a mathematical calculation that captures the impact of roughness.

A closed–form solution for axial flow, including different physical parameters has been obtained. Graphical and tabular diagrams suggest that the effect of longitudinal roughness on the performance is higher as compare to the transverse roughness pattern.

Additionally, it is observed that the eccentricity ratio plays a crucial role in improving bearing system.

Keywords:

- *Film thickness*
- *Axial flow,*
- *Deformable roughness*
- *Pressure distribution*

Nomenclature:

c	Radial clearance
e	Eccentricity ratio ($e = e_1 / c$)
h	Oil film thickness
e_1	Eccentricity
p_0	Oil feed pressure
D	Diameter of the hole
L	Axial length
P	Lubricant pressure
R	Radius of the hole
U	Shaft surface speed
ϕ	Permeability of porous facing
H_0	Minimum film thickness of porous facing
σ	Standard deviation
ε	Skewness
a	Variance
δ	deformation
θ	Circumferential co-ordinate
η	Dynamic viscosity of fluid
σ^*	Non-dimensional standard deviation
ε^*	Non-dimensional skewness
α^*	Non-dimensional variance
δ^*	Non-dimensional deformation
ψ	$12\phi H_0 / c$
dp/dx	Pressure gradient

Introduction:

The primary concern in a bearing lies in the makeup flow, which refers to the total side leakage or the amount of oil required maintaining the bearing's fullness. This makeup flow consists of two key elements: firstly, the disparity between the oil flows at the beginning and end of the pressure curve, and secondly, the oil that exits the bearing nears the inlet due to pressure feeding.

It is widely acknowledged that bearing surfaces, especially after experiencing wear and run-in, develop roughness. Additionally, lubricant contamination contributes to surface roughness through chemical degradation. The roughness typically exhibits a random nature without following a specific structural pattern. Moreover, it is well-established that friction increases with higher average roughness. Therefore, roughness parameters are crucial in various applications such as automotive braking systems, flooring surfaces, and tires.

The fundamental principles of axial flow rate were initially explored by Cameron [1], who devised a method for oil feeding through a hole typically situated on the load line. Recently, Zhang et al. [2] analyzed the operational performance and flow characteristics of an axial piston pump using computational fluid dynamics technology.

Several researchers have recognized the random nature of roughness and have attempted to analyze its effects. Christensen and Tonder [3]-[5] proposed a comprehensive analysis of surface roughness, both transverse and longitudinal, based on a general probability density function, building upon the work of Tzeng and Seibel [6]. Shukla and Deheri [7] studied the performance of a rough porous journal bearing and found that transverse roughness generally impacts bearing performance negatively.

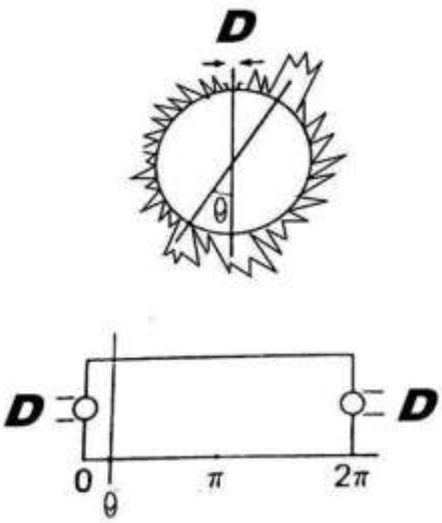
Recently Shukla S. D., Deheri G. B., [8] discussed a computational model of axial oil flow from a rough hole and found that eccentricity ratio plays a central role in bettering the performance of the system in presence of roughness.

Thus, it has been sought to develop a computational model of axial oil flow from a porous deformable rough hole-based bearing system.

Mathematical Analysis and Geometry:

Figure (A) indicate that the oil is fed in through a hole which is usually on the load line, opposite the load.

Figure: (A) Coordinate and Geometry of the bearing system



The local film thickness, which is the dominant factor for the flow, is then

$h = c\,(1 + e\cos\theta)$

(1)

Oil is normally fed into journal bearing in one of the way, which is a feed hole at the bearing split, ±90° to the load line. Assume the pressure drops linearly from groove to the outside bearing edge, so dy / dx = p_0 / (L/2). The total flow Q will be

$$Q = 2\int_0^{2\pi} \frac{h^3 dpRd\theta}{12\eta dx}$$

(2)

On the assumption dp / dx = $2p_0$ / L, D = 2R and Q_d^* = flow per unit length

Now, with the aid of stochastic average model of Christensen and Tonder (1969a, 1969b, 1970), one gets

$$Q = \left(\frac{a(h)\,p_0 D}{12\eta L}\right) Q^*{}_d$$

(3)

where

$a(h) = (h + p_a p'\delta)^3 + 3(\sigma^2 + \alpha^2)\,(h + p_a p'\delta) + 3\,(h + p_a p'\delta)^2\alpha + 3\sigma^2\alpha + \alpha^3 + \varepsilon + 12\phi H_0$ (4)

Using non – dimensional parameters:

$\varepsilon^* = \varepsilon/c^3$ $\sigma^* = \sigma/c$ $\alpha^* = \alpha/c$ $\delta^* = \delta/c^3$ $p^* = p_a p'$

(5a)

$Q^* = 12\eta L/Rc^3 p_0$

(5b)

$A(h) = a(h)/c^3$

(5c)

$A_1 = \varepsilon^* + 3\sigma^{*2}\alpha^* + \alpha^{*3} + 12\psi$

(5d)

$A_2 = 3(\sigma^{*2} + \alpha^{*2})\,(1 + p^*\delta^*)$

(5e)

$A_3 = (1 + p^*\delta^*)^3 + 3\alpha^*(1 + p^*\delta^*)^2$

(5f)

and fixing the following symbols

$Q_1 = 1 + A_1 + a_2 + a_3$ (6a)

$Q_2 = e\,A_2 + 2e\,A_3 + 3e$

(6b)

$Q_3 = e^2\,A_3 + 3e^2$

(6c)

$Q_4 = e^3$

(6d)

One obtains the formulation for axial flow rate in the dimensionless form

$$Q^* = \frac{1}{Q_1 + Q_2\cos\theta + Q_3\cos^2\theta + Q_4\cos^3\theta} Q^*{}_d$$

(7)

Results and discussions:

The non-dimensional axial flow rate distribution, as derived from Equation (7), reveals a notable impact of the roughness parameters such as: standard deviationσ^*, variance α^*, skewness $\varepsilon^*$and also inclusion of deformation. The presence of roughness impedes lubricant motion, leading to reduced pressure and consequently diminished axial flow rates.

Tables (1) to (7) demonstrate that the axial flow rate increases with variations in standard deviation and variance. Additionally, surface deformation significantly impacts the results. The numerical values provided offer clear insights into the design of this type of bearing system.

Table No.				**Minimum**	**Maximum**	**Difference (%)**
1	σ^*	$\rightarrow$	α^*	1.81883830	2.22069873	0.4418
2	σ^*	$\rightarrow$	ε^*	0.22496579	2.55936378	20.7534
3	σ^*	$\rightarrow$	e	1.86380443	2.31547004	0.4846
4	σ^*	$\rightarrow$	θ	1.62504802	2.12234746	0.612
5	σ^*	$\rightarrow$	δ	1.62802715	2.12234746	0.6072
6	σ^*	$\rightarrow$	P*	1.62504802	2.10323477	0.5886
7	σ^*	$\rightarrow$	ψ	2.00480469	2.35339411	0.3478

Findings and conclusions:

This investigation strongly suggests that the roughness must be addressed while designing the bearing system. From this study, the following conclusions can be drawn:

- The eccentricity ratio offers some help in reducing the adverse effect of standard deviation in the case of negatively skewed roughness. Further, this effect enhances when variance (-ve) occurs.
- Although, there are many factors reducing the axial flow rate, the standard deviation is at considerably low level.

Credit Author ship Contribution Statement:

Rakesh M. Patel	Mathematical justification and validation.
Prin. Dr. Pragna A. Vadher	Writing and conceptualization.
Dr. Sanjeev Kumar	Verification with the application.
Dr. Gunamani B. Deheri	Mathematical justification of the problem.

Declaration of Competing Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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