DISCUSSION

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The authors are to be commended for applying hydrodynamic lubrication theory to the lubrication of piston skirts. At the General Motors Research Laboratories we have been studying this problem for a number of years and have had some success in the use of such hydrodynamic lubrication analyses. We have primarily been concerned with the quantification and reduction of piston skirt friction—although the applicability of these analyses to piston noise has also been studied.

For a given set of kinematics, the authors have computed the fluid film pressure distribution and the resulting load capacity and moment about the piston pin axis. From a design point of view, however, it is the inverse problem which is of most interest and which we have addressed. The inverse, or dynamically loaded bearing problem, consists of being given the loads on the bearing and the tangential relative velocity between bearing surfaces and then calculating the film thickness trajectory. Hence, using the authors's notation, we have formulated the problem as:

$$m_p \ddot{\epsilon} + S_0(t, \epsilon, \dot{\epsilon}, q, \dot{q}) = \bar{W}(t)$$

$$I_p \ddot{a} + \hat{M}_k (t, \epsilon, \dot{\epsilon}, q, \dot{q}) = \bar{M}(t)$$

where $\bar{W}(t)$ and $\bar{M}(t)$ are normalized loads and moments applied to the piston skirt, respectively; $\hat{M}_k$ corresponds to M_k but includes the moment due to piston skirt friction; and m_p and I_p represent the piston mass and moment of inertia about the piston pin. The inertia and gas pressure forces on the piston are used to compute $\bar{M}$ and $\bar{W}$. Periodic solutions for ϵ and q as functions of time are then obtained. Figure 12 shows a typical result obtained in this study [10]. It illustrates the predicted motions at the top and bottom of the piston skirt of an automotive engine under firing conditions. This information was utilized to improve the understanding of engine dynamics and the capability to predict the mechanical friction in automotive engines.

The authors also discuss the application of the finite element method (FEM) to lubrication problems. This methodology is well known [11, 12]. The more interesting aspect of this problem, however, is the determination of the free boundary when p and $\partial p/\partial n$ both vanish. Reference [13] discusses a simple method for obtaining that boundary using FEM. Could the authors comment on what their iteration method was?

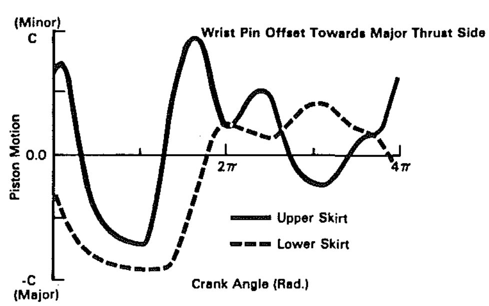

Fig. 12 Dynamics of automotive piston

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Additional References

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11 Reddi, M. M., "Finite Element Solution of the Incompressible Lubrication Problem," Trans. ASME, Series F, Vol. 91, pp. 524-533, 1969.

12 Booker, J. F. and Huebner, K. H., "Application of Finite-Element Method to Lubrication: An Engineering Approach," Trans. ASME, Series F, Vol. 94, pp. 313-323, 1972.

13 Rohde, S. M. and McAllister, G. T., "A Variational Formulation for a Class of Free Boundary Problems Arising in Hydrodynamic Lubrication," International Journal of Engineering Science, Vol. 13, pp. 841-850, 1975.

Authors' Closure

(All the used notations, references and equation numbers are the same as of the paper).

For the free boundary of a convergent-divergent lubricating film it's satisfactory enough to apply the conditions for the pressure distribution, for which p and $\partial p/\partial n$ both vanish. By evaluation of the free boundary we have to deal use with an iterative method.

In the literature we find various methods to solve this problem (e.g. [5], [8]). An alternative method provides the equation (14.2). To satisfy the 2nd condition $\partial p/\partial n = 0$, we have to set the integral $\int_{\Gamma_F} = 0$.

The 1st condition is full-filled when the coordinate φ_E of the pressure boundary is identical with the free boundary. The evaluation of the free boundary angle φ_E is well done by means of an iterative method.

Figure 1 shows the principle of various iteration steps. The free boundary is approximately satisfied and step $n + 1$ in an iterative manner.

This method provides a good convergence even under extreme eccentricity conditions.

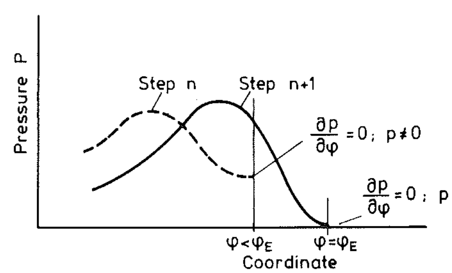

Fig. 13 Iterative method for free boundary