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A new efficient flow continuity lubrication model for the piston ring-pack with consideration of oil storage of the cross-hatched texture

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ABSTRACT

In this paper, a new efficient flow continuity lubrication model for the piston ring -pack is established by taking the oil storage of the cross-hatched texture into account. To fully consider the influence of the cross-hatched texture and plateau roughness on the lubrication and oil transport, a two-dimensional two-scale mass-conserving homogenized mixed lubrication model is developed. To solve the mass-conserving model efficiently, the recently proposed Fischer-Burmeister-Newton-Schur (FBNS) algorithm is adopted. The oil available to lubricate each ring is determined by conducting an oil transport analysis. The trapped oil in the texture is calculated as an extra oil supply to the inlet of the contact. The developed model has great potential for understanding and optimizing the honed cylinder liner surface.

1. Introduction

In an internal combustion engine, the lubrication behavior of the piston ring-pack is of significant importance. Experimental evidence has shown that the top two rings usually operate under starved lubrication condition during an engine cycle, which indicates that the piston ring-liner interface is not fully covered with oil [1–4]. Therefore, lubricant starvation is a typical feature of the piston ring-liner contact. The oil supply available to each ring of the ring-pack should be determined by ensuring the flow continuity condition [5–9]. It is generally considered that the oil available to lubricate the successive rings depends on the passage of the preceding ring to some extent.

The piston ring-liner interface is composed of two partially-filled regions and a fully-filled region [9]. The starting point of the fully-filled region at the inlet is defined by starved lubrication, while the termination point of the fully-filled region at the outlet is defined by cavitation. In hydrodynamic lubrication, the Reynolds boundary condition and the JFO boundary condition are two boundary conditions generally used to define the rupture boundary at the outlet. The former is easier to implement numerically, and the predictions are reasonable in many cases. However, it is non-conservative. The JFO boundary condition proposed by Jacobson and Floberg [10] and Olsson [11] is based on mass conservation principle. Furthermore, both the rupture and reformation boundaries of the oil film can be determined by this boundary condition effectively. Later, Elrod and Adams (EA) [12] proposed an improved algorithm for the JFO boundary condition. However, there is a long-standing problem in solving these mass-conserving models. This kind of problem is highly non-linear, thus, the numerical solutions are more unstable [13]. It has been also demonstrated that a mass conservative model is necessary to conduct an accurate prediction of the lubrication performance, especially for transient problems and problems with microtextures [14,15]. Furthermore, it is complicated and time-consuming for the determination of the inlet and outlet boundaries simultaneously. Therefore, an efficient and stable conservative solution of pressure and cavitation distributions is required. Recently, by reformulating the EA implementation of the JFO cavitation conditions, Woloszynski et al. [16] proposed an efficient algorithm, called Fischer-Burmeister-Newton-Schur (FBNS) algorithm, to solve the cavitation model. Compared with the traditional algorithms [14,17,18], the FBNS algorithm is substantially faster, and the computing time can be reduced by roughly two orders of magnitude. It is promising in solving these mass-conserving models.

Recently, surface texturing has drawn much attention as surface texturing is capable of improving the tribological properties of sliding friction pairs. In the automobile industry, the cylinder liner is usually produced by the honing process to enhance performance. The final honed liner surface is composed of plateaus and valley components (cross-hatched textures). These two components play different roles in the ring-

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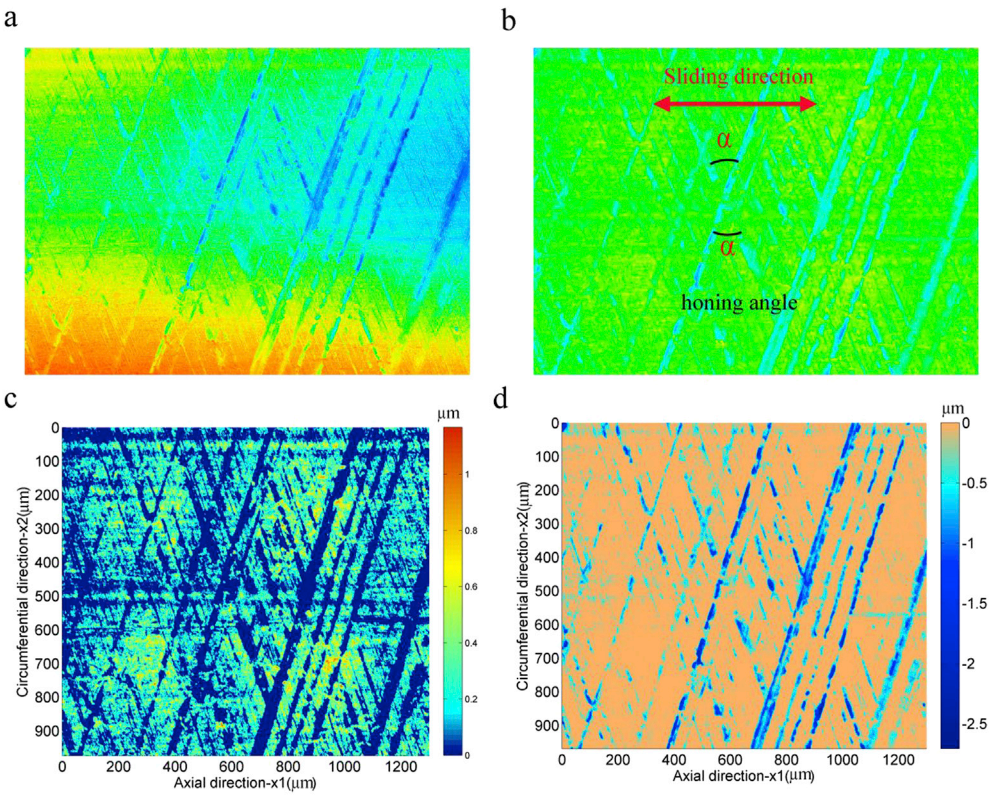

Fig. 1. Decomposition of the measured cylinder liner surface: (a) the measured surface topography; (b) the acquired surface after removing the form elements; (c) the plateau component; and (d) the valley component.

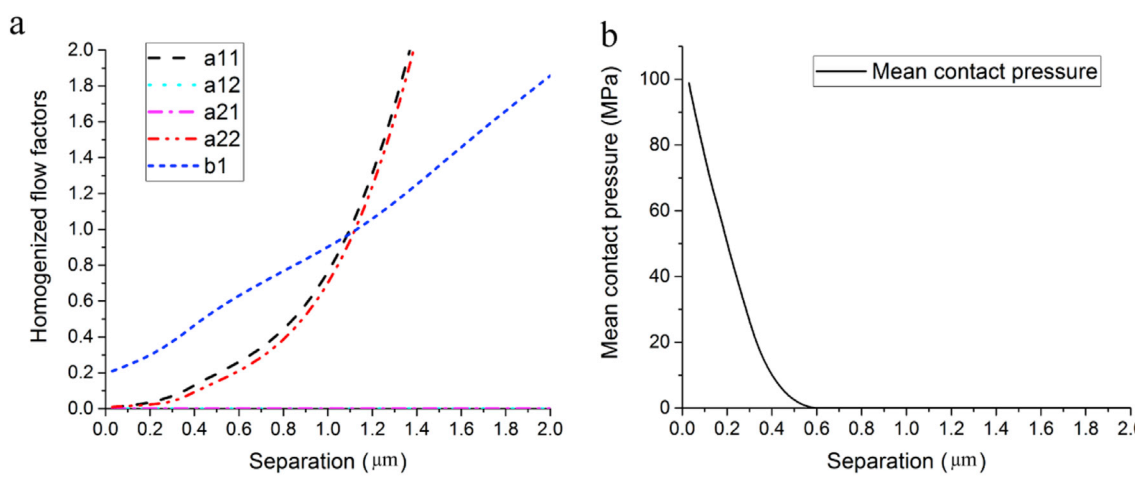

Fig. 2. (a) Variation of the homogenized flow factors with the separation; (b) Variation of the mean contact pressure with the separation.

liner contact. The plateau component is related to friction and wear, and the cross-hatched texture is related to lubricant circulation and retention. Micro-texture is generally recognized as micro-bearing to provide a hydrodynamic lift. This micro-hydrodynamic effect has been studied extensively, however, opposite conclusions have been drawn in these studies. Particularly for the cross-hatched texture, it was demonstrated by Bouassida et al. [19] that the load carrying capacity (LCC) of the barrel-shaped top ring is decreased by the cross-hatched texture. However, Bouassida et al. [20] showed that a certain LCC can be generated by the cross-hatched texture for a flat ring, which has no LCC. Hu et al. [21] studied the effects of the cross-hatched texture on the friction performance of the ring-liner system by taking the ring profile, operating conditions and plateau roughness into consideration. It was assumed fully-flooded lubrication condition in the above studies, which is usually not the case in an actual engine, especially for the top two rings. Therefore, much attention should be paid to the study of the performance of the cross-hatched texture under starved lubrication condition. Another important function of the cross-hatched texture is lubricant circulation and retention. This function is likely to be more significant under starved lubrication. Actually, the cross-hatched texture is more beneficial for oil circulation and retention than the dimple texture. The oil can be constantly replenished owing to the oil circulation in the cross-hatched texture. However, the lubricant circulation and retention of the cross-hatched texture is rarely involved in the published literature.

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