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A UNIFIED APPROACH FOR SURFACE CONTACT AND LUBRICATION PROBLEMS

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ABSTRACT

Power and motion are typically transmitted through surface contact (dry or lubricated) in various machine elements (such as gears, bearings, joints, engine and hydraulic parts, metal-forming/metalworking tools, computer drives, and artificial human joints, etc). A good understanding of contact stress, deformation, lubrication effectiveness, interfacial friction and temperature as well as surface failure mechanisms is extremely important for studies of mechanical system performance, durability, efficiency and energy/ materials consumption. Dry contact models developed can be applied to simulate those components working under dry contact conditions. The first counterformal dry contact model was developed in 1882 by Hertz based on smooth surface and perfect geometry assumptions. For most engineering surfaces whose roughness cannot be ignored, however, satisfactory dry contact deterministic solutions did not appear until recently. Advanced FFT-based dry contact models can now quickly predict contact stresses and deformation, taking into account real roughness/topography, plasticity, thermal effect and functionally graded materials and coating layers. These models include the ones by Ju & Farris (1996), Stabley & Kato (1997), Hu, Barber & Zhu (1998), Ai (2000), Polonsky & Keer(2000), Liu and Wang (2001-2003), Chen and Wang (2007), and others. For components working with fully lubricated contacts, where surfaces are completely separated with a lubricant film, full-film hydrodynamic/elastohydrodynamic lubrication theories have been developed by Reynolds (1886), Martin (1914), Dowson and Higginson (1959) and Hamrock and Dowson (1976), and others, under the same smooth surface assumption. Lubrication models considering real engineering surface roughness may employ either stochastic approaches, such as those by Patir and Cheng (1978), Zhu and Cheng (1988), and Harp and Salant (2001), or deterministic simulations, such as those by Xu and Sadeghi (1996) and Zhu and Ai (1997), and others. Basically, dry contact models and full-film lubrication models have been reasonably well developed, as they deal individually with either surface dry contact or pure hydrodynamic lubrication. Currently used dry contact models are different from those for lubrication.

However, most functional machine elements operate in the mixed lubrication regime, where both surface contact and hydrodynamic lubrication coexist. For powertrain components such as gears, bearings, pistons/rings and cams/followers, for example,

operating conditions are often severe and the roughness of machined surfaces are usually of the same order as, or greater than, the lubricant film thickness. As a result, power is transmitted through rough surface asperity contacts in some areas and lubricant film in other areas, and neither contact nor lubrication can be ignored. A simulation model for mixed lubrication, therefore, must deal with surface contact and lubrication simultaneously. The importance of the mixed lubrication study can never be overestimated, as it is fundamental to lubrication effectiveness, efficiency, durability and reliability of many mechanical components.

The key question in the mixed lubrication study is how to model surface contact and hydrodynamic lubrication simultaneously. There are basically two types of models. The first simulates contact and lubrication separately with different approaches. For contact, a dry contact model is used, while for lubrication the Reynolds equation is employed. Boundaries between the contact areas and the hydrodynamically lubricated areas need to be determined and boundary conditions need to be handled properly. This may be rather challenging if machined surfaces with random or irregular surface roughness is involved, and, especially, if the contact areas keep changing and the problem is highly transient.

The second type of approach has concurrently been developed by Hu and Zhu [1], Zhu and Hu [2](2001), Holmes et al (2005), Liu, Wang and Zhu et al (2006) and others, using a unified model for solving both contact and lubrication simultaneously with the same Reynolds equation system. Since dry contact is an extreme case of lubricated contact at ultra-low viscosity and/or ultra-low speed, theoretically dry contact can be simulated within lubrication models as long as the numerical solver is sufficiently robust to handle ultra-low viscosity and/or ultra-low speed. With this approach, determination of boundaries and special handling of boundary conditions between the contact and lubrication areas are no longer needed, and the solution procedure becomes straightforward and relatively simple.

This paper describes the unified approach for mixed lubrication in detail. It also presents model validation examples, which have shown that, based on the unified simulation model with the same Reynolds equation system, obtained results agree with conventional lubrication theories and numerical/experimental data from other researchers very well when the lubricant film is sufficiently thick to separate the surfaces. If the speed is ultra-low, solutions from the same unified approach match with those from FFT-based dry contact models perfectly. When the speed is gradually increased, sample solutions demonstrate a continuous and smooth transition from the dry contact to mixed and all the way to full-film hydrodynamic lubrication. The unified model appears to be satisfactory for handling cases in a wide range of operating conditions. It shows a good potential for further development in both contact/lubrication theories and engineering practice.

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