A combined Cellular Automata/FFT based tool for modelling third body flows

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Abstract

Modelling the third body behaviour in dry contacts remains a significant challenge in tribology. The third body, a layer located at the interface between two bodies in contact, arises from the conceptualization of dry contact proposed by Godet in the 70s (1). His aim was to establish a link between solid and fluid lubrication in the treatment of contact problems. This layer is liquid in fluid lubrication problems, while in dry contact scenarios, it is solid and composed mainly of debris particles. In a closed contact, third body plays a crucial role in friction and wear processes. However, in these conditions, 'in situ' experimental measures are challenging to conduct. Many scientists have turned to numerical approaches to complement the experimental study of third body behaviour.

Still, selecting an appropriate model is complicated by several factors. The significant difference in scales between the third body and the first bodies presents a primary challenge. Indeed, the thickness of the third body is often smaller by four or five orders of magnitude than that of the first bodies. Additionally, the multiphysics nature of the problem, involving mechanical, thermal, and chemical interactions, adds layers of complexity. The continuous reshaping of the bodies due to wear processes further complicates the modelling approach. Consequently, the choice of an appropriate modelling tool is highly dependent on the specific characteristics of the system under study; for instance, its size, its simulation time, or the physics studied. Each of these factors plays a crucial role in determining the most suitable modelling approach for accurately representing the tribological behaviour of the system.

To adress these modelling challenges, researchers have developed and adapted various numerical methods to study tribological phenomena across different scales. Amongst them, two methods are commonly used: the FEM (Finite Element Method), and the DEM (Discrete Element Method). The challenges of FEM lie both in understanding the phenomenology and in improving the convergence and performance of the models. Thus, to obtain relevant results, it is necessary to adjust the mesh refinement as needed. Consequently, when modelling a contact, the mesh must be refined at the interface, which leads to very significant computational costs. Moreover, the third body layer is not always homogeneous or continuous. The FEM being a continuous approach, the modelling of wear and the consideration

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of the third body layer is thus complicated and computationally expensive. The DEM may seem more relevant to represent a discontinuous media as the third body layer. In addition, the discrete models can represent both the fluid and solid behaviour of the third body, and can take into account the physico-chemical interactions between the particles. Despite these qualities, these models are suitable for a limited number of particles, a short simulation time, generally limited to 2D, and entail a high computational cost.
Even with FEM/DEM dialogues, the computational cost remains unfit for engineering applications.

To account for the different flows present in a contact (2), some questions should be solved:
1) How does the third body move at the contact, depending on the velocity, the roughness on the surfaces, etc.?
2) Why and how is the third body created?
3) How does the third body get out of the contact?
4) How can we efficiently simulate a macroscopic system over a long period with reduced computation time?

While some models found in the literature have provided insights to address our questions individually, none of them offer a comprehensive and precise description of the entire system. These questions led to the creation of an original approach, based on a dialogue between a Boundary Element Model (BEM) accelerated by Fast Fourier Transform (FFT) (3), and a Cellular Automata (CA) approach (4). The BEM calculates the quasi-static mechanical equilibrium between two rough surfaces. The resulting pressure and displacement fields feed the CA model, which aims to represent the creation and distribution of the third body in the moving system.

Knowing the surface roughness and the local third body thickness, the BEM model calculates the pressure and displacements fields as functions of the applied pressure. These fields are used as input for calculating the third body flows. The CA models a slight movement between the two surfaces, changing the spatial configuration at the contact. Depending on this new configuration, and on CA rules describing the mechanical and physico-chemical behaviour of the third body, the layer redistributes itself. Then, local pressure information is used to calculate the generation of the third body. The resulting spatial configuration is introduced in the BEM algorithm, and the process continues. The low computational time allows the calculation of the system evolution over a long time.

The novelty and originality of this approach lie in the CA model developed, and its dialogue with the BEM. This dialogue between the two models allows for a comprehensive simulation of tribological phenomena across multiple scales. The versatility of the CA rules enables the method to be neither system or material-dependant, making it highly adaptable. Importantly, this approach authorizes multiscale simulations while keeping computational times low. This balance between multi-scale capability and computational efficiency makes our approach a valuable tool for analysing complex contact behaviours.
This method will provide information on the coefficient of friction and enable parametric studies on various factors. For instance, on surface roughness, as well as on various conditions of pressure, temperature, speed, and others.

References:
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