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Constriction resistance of rough surfaces in contact

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Abstract: We study the thermal and electric resistance of individual contact clusters of complex shapes. Notably, we study how the connectedness of the spot and its geometrical compactness affect its conductivity. Further, we extend our study to contact zones made of many spots with and without oxide layers. This study was carried out using the fast boundary element method based on hierarchical matrices. Details of its implementation and a comparison with the finite element method are provided.

Keywords: Contact, roughness, electrical resistance, BEM, oxides

1 Introduction

Most engineering and natural systems involving contact between parts operate outside thermodynamic equilibrium and often involve thermal fluxes. Internal combustion engines (vehicles and aircrafts) and sliding of faults in the Earth's crust are two remarkable examples of relevant systems. The conductivity of contact interfaces is strongly dependent on the roughness of contacting solids, interfacial fluid and mechanical loads. The main thermal exchange between rough surfaces happens through intimate contact spots (true contact area). The thermal and also electric conductivity through such spots depend not only on the true contact area fraction but also on its morphology. The two of them evolve under the external load. Holm [1] and Greenwood [2] were among the first who realized the origin of the contact resitance and suggested simple models based on a set of interacting circular contact spots representing true contact area. However, at higher loads, the true contact area cannot be represented by a set of circular or elliptic spots but rather by complex not simply connected clusters [3] which represent the topic of this study. Furthermore, the morphology of contact clusters and the true contact area could be affected by thermal, chemical and metallurgical effects. Especially, formation of weakly conducting or insulating oxide layers strongly affect electrical resistance of contact interfaces.

1.1 Methods

To conduct the study on conductivity of contact spots of complex shape and their agglomerates Figs. 1,2, we implemented a fast boundary element method (fast-BEM) based on hierarchical matrices [4]. Such a method allows to overcome the main drawback of the classical BEM: storage and resolution of full matrices, which used to be a bottle neck of the method compared to the classical FEM. The problem of conductivity in contact interface reduces to the following integral equation

$$u(\boldsymbol{x}) = \int_{\partial\Omega_c} j_n(\boldsymbol{y}) G(\boldsymbol{x},\boldsymbol{y}) dS \tag{1}$$

which should be solved for all contact clusters $\partial\Omega_c$ with u being the potential/temperature and j_n being the normal flux, $G(\boldsymbol{x}, \boldsymbol{y})$ is the Green function. This problem formulated for half-spaces is well adapted for the BEM, whose implementation will be presented in detail. Apart from simplified model shapes, we also study shapes resulting from contact simulations based on a spectral method. We demonstrate how the BEM and spectral method could operate efficiently together to solve weakly coupled multiphysical problems.

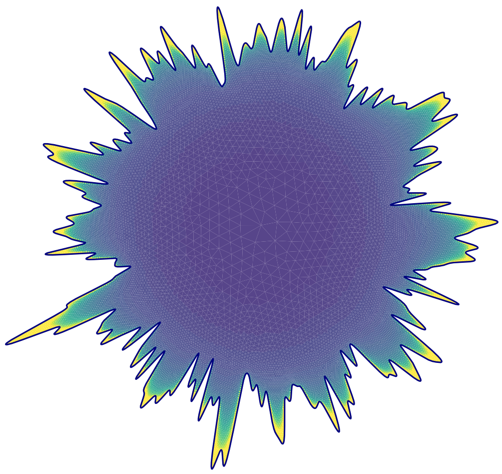

Figure 1: Simulated normal flux through a contact spot with random self-affine boundary

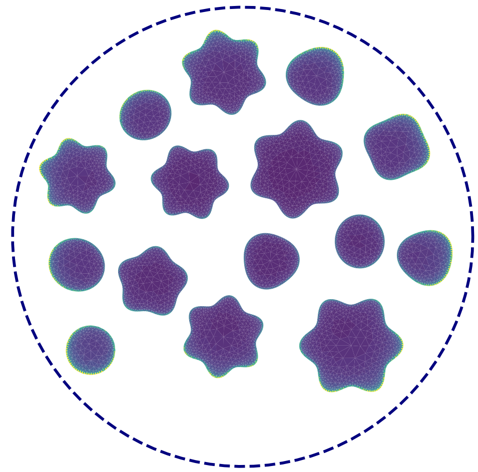

Figure 2: Simulated normal flux throug a multi-spot contact area

2 Results & Discussion

Several novel results on the conductivity of complex shapes were obtained thanks to the powerful fast-BEM, notably we established a relationship between fractal dimension and spectral breadth of a contact spot and its conductivity. For the multi-spot configuration we established limits of applicability of the Greenwood's model [2]. Finally, a method to take into account effect of oxide layers was established for different types of oxide.

References

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