The Method of Dimensionality Reduction, a universal tool for simulation of dynamic systems with contact and friction

Markus Heß, Valentin L. Popov

Technische Universität Berlin, Sekr. C8-4, Straße des 17. Juni 135, 10623 Berlin, Germany
E-Mail: markus.hess@tu-berlin.de

Abstract

The mapping of contact interfaces within the simulation of dynamic systems is still a challenging task for many engineers. For this reason, we have developed the so-called "Method of Dimensionality Reduction" (MDR), which maps the complex three-dimensional contact interface onto a simple one-dimensional model [1]. As a common feature of many models, this results in a significant reduction of degrees of freedom. However, In contrast to all conventional models, *MDR does not provide an approximate solution, but reproduces exactly the results of three-dimensional contact mechanics*. This property holds true regardless of the type of contact, the contact geometry and is not limited to elastic contacts, but includes contacts between visco-elastic materials as well as certain classes of functionally graded materials [2]. In addition to this key feature of obtaining exact results despite of the significant reduction in the degrees of freedom, MDR is extremely easy to handle. Simulations of contact properties by using MDR are extremely fast, so that they can be implemented directly within macroscopic system dynamic simulations.

In this talk we will briefly introduce the basics of MDR. In particular we will illustrate its application within the simulation of frictional systems by selected examples. The examples are taken from a variety of applications in which MDR has proven to be highly suitable. These include stick-slip micro-drives, which are used to move objects due to asymmetric periodic excitation [3] and also impacts of elastic and visco-elastic particles, including molecular adhesion, which are of interest in many physical and technological processes related to the dynamics of granular media [4][5]. Other applications are the active control of friction by in-plane and out-of-plane oscillations [6][7] as well as shakedown and creep in oscillating rolling contacts [8]. Furthermore, MDR allows the calculation of fretting wear including the limiting wear shape, which can be used for designing fretting wear resistant joints [9][10][11]. MDR was also used to investigate frictional and relaxation damping due to simultaneous oscillations in both normal and tangential directions [12][13]. The results may be used for designing and tuning the structural damping of systems with frictional contacts. The numerical simulation results agree well with available measurement results of suitable experiments.

References

Popov, V. L., Heß, M. (2015). *Method of dimensionality reduction in contact mechanics and friction*. Springer-Verlag, Berlin

1. Heß, M., Popov, V. L. (2016). Method of dimensionality reduction in contact mechanics and friction: a user's handbook. II. Power-law graded materials. *Facta Universitatis, Series: Mechanical Engineering*, *14*(3), 251-268.
2. Teidelt, E., Willert, E., Filippov, A. E., Popov, V. L. (2012). Modeling of the dynamic contact in stick-slip microdrives using the method of reduction of dimensionality. *Physical Mesomechanics*, *15*(5-6), 287-292.
3. Lyashenko, I. A., Willert, E., Popov, V. L. (2016). Adhesive impact of an elastic sphere with an elastic half space: Numerical analysis based on the method of dimensionality reduction. *Mechanics of Materials*, *92*, 155-163.
4. Argatov, I. I., & Popov, V. L. (2016). Rebound indentation problem for a viscoelastic half-space and axisymmetric indenter—Solution by the method of dimensionality reduction. *ZAMM-Journal of Applied Mathematics and Mechanics*,, *96*(8), 956-967.
5. Popov, M., Popov, V. L., & Popov, N. V. (2017). Reduction of friction by normal oscillations. I. Influence of contact stiffness. *Friction*, *5*(1), 45-55.
6. Mao, X., Popov, V. L., Starcevic, J., Popov, M. (2017). Reduction of friction by normal oscillations. II. In-plane system dynamics. *Friction*, *5*(2), 194-206.
7. Wetter, R., & Popov, V. L. (2014). Shakedown limits for an oscillating, elastic rolling contact with Coulomb friction. *International Journal of Solids and Structures*, *51*(5), 930-935.
8. Dimaki, A. V., Dmitriev, A. I., Chai, Y. S., Popov, V. L. (2014). Rapid simulation procedure for fretting wear on the basis of the method of dimensionality reduction. *International Journal of Solids and Structures*, *51*(25-26), 4215-4220.
9. Dmitriev, A. I., Voll, L. B., Psakhie, S. G., Popov, V. L. (2016). Universal limiting shape of worn profile under multiple-mode fretting conditions: theory and experimental evidence. *Scientific reports*, *6*, 23231.
10. Popov, V. L. (2014). Analytic solution for the limiting shape of profiles due to fretting wear. *Scientific reports*, *4*, 3749.
11. Dimaki, A. V., Pohrt, R., Popov, V. L. (2017). Simulation of frictional dissipation under biaxial tangential loading with the method of dimensionality reduction. *Facta Universitatis, Series: Mechanical Engineering*, *15*(2), 295-306.
12. Popov, M., Popov, V. L., Pohrt, R. (2015). Relaxation damping in oscillating contacts. *Scientific reports*, *5*, 16189.