Contact pressure profile influence on wear prediction for MBS revolute joints models.

Mario López-Lombardero[1], Javier Cuadrado[2], Mario Cabello[1], Félix Martínez[1], Daniel Dopico[2], Álvaro López-Varela[2],

[1]Ikerlan Research Center
Pº, J. M.ª Arizmendiarreta, 2
20500, Arrasate-Mondragón, Spain
[mlopez, mjcabello, felix.martinez]
@ikerlan.es

[2]Lab. of Mechanical Engineering
University of La Coruña
Mendizabal s/n, 15403, Ferrol
[javier.cuadrado, daniel.dopico,
alvaro.lopez1]@udc.es

EXTENDED ABSTRACT

Wear is a phenomenon that affects all types of joints present in machines, and therefore it must be taken into account in mechanism simulations. Although the topic of simulation of joints with clearance has been widely studied by the scientific community of Multibody Dynamics (MBD), their simulation considering wear is not as frequent. Some remarkable works can be found in [1-4].

Consideration of wear in the simulation often leads to a gradual increase of the contact forces at the joints caused by the evolution of the clearance size. This growth of the joint clearance together with the increase of the contact forces lead to a progressive degradation of the machines, as shown in [5].

A correct modelling of wear can be of great help for a more realistic simulation of the behaviour of the mechanisms, which may allow to estimate how the performance of the machines evolves over time. In most works of MBD, wear is modelled by means of Archard equation [6]. This equation represents a proportional relation between the wear volume and the product of normal force and relative slip, as gathered in Eq.1.

$$V = K_w \cdot F_n \cdot s \tag{1}$$

$$h_n^i = h_n^{i-1} + K_w \cdot p_n \cdot \Delta s \tag{2}$$

Eq.2 corresponds to the Archard equation developed for obtaining a wear depth at point n at instant i. What is obtained by applying the Archard equation is an accumulated wear due to the numerical integration with respect to time and space of the wear produced at each time step.

In a previous work [7], the importance of a good spatial and temporal discretisation for the correct modelling of wear was discussed. It was concluded that, for wear to be considered properly, there must be some overlapping between the pressure profiles at each time step. Pressure profiles determine the instantaneous wear profiles, which lead to wear increment along time.

The overlapping between the instantaneous wear profiles is critical for a good wear estimation. It depends mainly on the relative tangential velocity and the time step used. However, these are not the only factors that must be taken into account. In some works [1, 3, 8, 9], it has been observed that, when computing wear, the Hertz contact pressure is not applied, but a uniform contact pressure is assumed instead for the sake of simplicity. This simplification can lead to large irregularities in the estimated worn geometry.

Differences between the consideration of a Hertzian pressure distribution and a uniform pressure profile over the entire contact area are illustrated in Figure 1, where it can be seen that the application of a contact profile according to the Hertz theory generates a more uniform wear in the final geometry of the worn bushing.

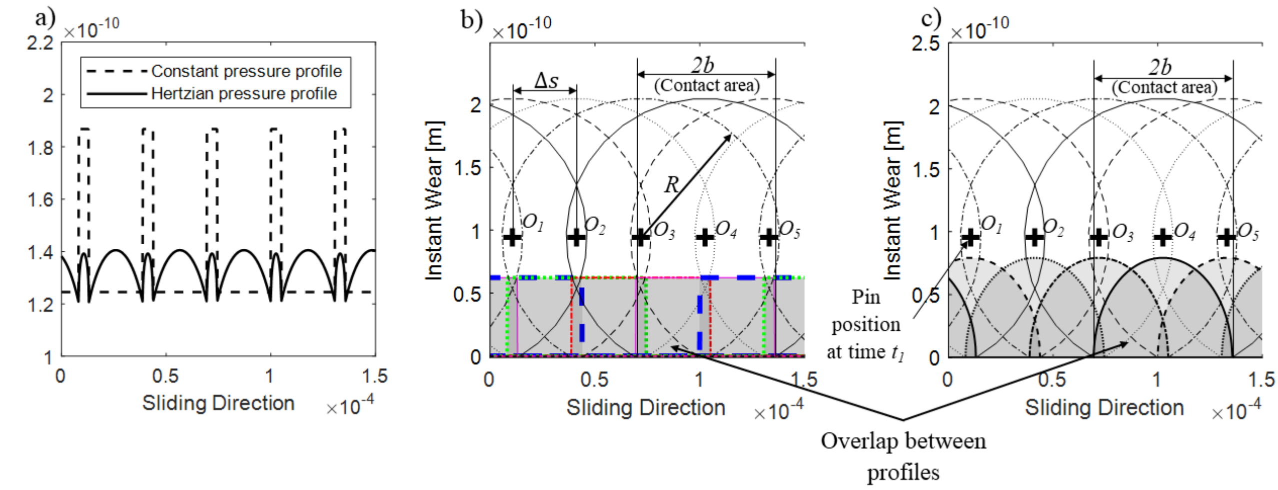

Figure 1. Differences in accumulated wear due to different pressure distributions: a) accumulated wear for each pressure distribution; b) Instant wear for uniform pressure profile; c) Instant wear for Hertzian pressure profile.

The results in Figure 1 assume a cylinder-cylinder contact, in which sliding occurs at constant speed under a normal force. It can be seen that, in the case of application of the uniform pressure profile, the result in the accumulated wear follows a stepwise form, as constant values are added according to the overlapping of profiles of different time steps. Whereas, in the case of consideration of the Hertzian contact pressure profile, wear is calculated as a function of the distance to the contact point according to the elliptical Hertz distribution. It is observed that the accumulated wear resulting in this case is more homogeneous than in the previous case.

In order to study the impact of this effect on the simulation of a mechanism, a slider-crank mechanism has been simulated. The mechanism has a clearance joint at the connecting rod-slider joint, the bushing belonging to the connecting rod. As can be seen in Figure 2, the use of a uniform pressure distribution leads to some irregularities in the worn profile of the bushing, which are greatly reduced when using the Hertzian pressure distribution.

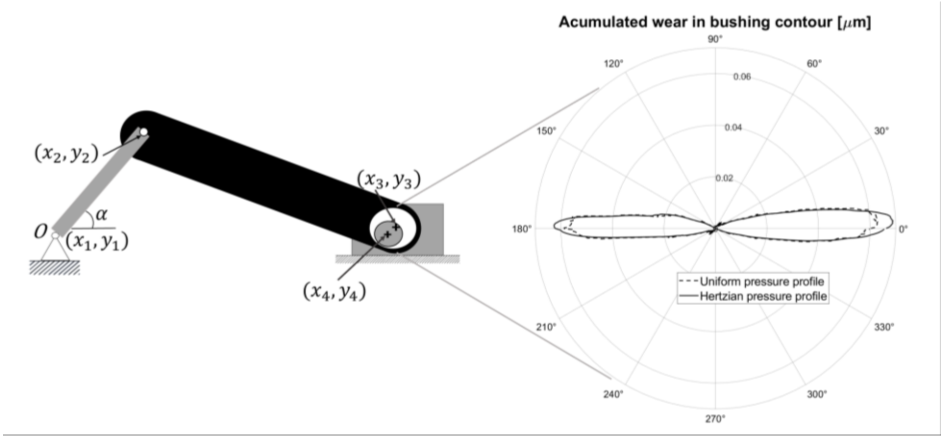

Figure 2. Slider-crank mechanism: a) joint with clearance; b) accumulated wear at the joint after one cycle.

The presence of irregularities in the bushing contour introduces non-linearities in the system, which may hinder the simulation due to problems in the numerical integration and can lead to inaccurate wear predictions. From the obtained results, the application of the Hertz contact pressure profile instead of the uniform pressure profile is recommended for several reasons: (i) it is a more accurate distribution as it comes from an analytical formula obtained from the Hertz contact theory; (ii) it is simple to implement and does not involve great computational cost; (iii) it provides a more uniform and continuous wear prediction, which means that there are no abrupt jumps in contact penetration or force, which facilitates the simulation and provides better prediction of bushing wear.

References

[1] P. Flores, J. Ambrósio, J. C. P. Claro, and H. M. Lankarani, "Modeling expected wear in revolute joints with clearance in multibody mechanical systems.," presented at the 6th International Conference on Multibody Systems, Nonlinear Dynamics, and Control, Parts A, B, and C., Las Vegas, Nevada, USA, September 4-7, 2007.

[2] S. M. Mukras, N. A. Mauntler, N.-H. Kim, T. L. Schmitz, and W. G. Sawyer, "Dynamic modeling of a slider-crank mechanism under joint wear," 2008.

[3] Z. Bai, Y. Zhao, and X. Wang, "Wear analysis of revolute joints with clearance in multibody systems," *Science China Physics, Mechanics and Astronomy,* vol. 56, no. 8, pp. 1581-1590, 2013, doi: 10.1007/s11433-013-5125-2.

[4] L. X. Xu and Y. C. Han, "A method for contact analysis of revolute joints with noncircular clearance in a planar multibody system," *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-body Dynamics,* vol. 230, no. 4, pp. 589-605, 2016, doi: 10.1177/1464419316644880.

[5] M. Ordiz, J. Cuadrado, M. Cabello, I. Retolaza, F. Martinez, and D. Dopico, "Prediction of fatigue life in multibody systems considering the increase of dynamic loads due to wear in clearances," *Mechanism and Machine Theory,* vol. 160, 2021, doi: 10.1016/j.mechmachtheory.2021.104293.

[6] J. F. Archard, "Contact and Rubbing of Flat Surfaces," *Journal of Applied Physics,* vol. 24, 1953.

[7] M. López-Lombardero, J. Cuadrado, M. Cabello, and F. Martinez, "Numerical considerations for simulating wear in revolute joints," presented at the The 6th International Conference on Multibody System Dynamics and The 10th Asian Conference on Multibody System Dynamics, New Delhi, India, 2022.

[8] L. X. Xu, Y. C. Han, Q. B. Dong, and H. L. Jia, "An approach for modelling a clearance revolute joint with a constantly updating wear profile in a multibody system: simulation and experiment," *Multibody System Dynamics,* vol. 45, no. 4, pp. 457-478, 2018, doi: 10.1007/s11044-018-09655-z.

[9] X. Chen, Y. Tang, and S. Gao, "Dynamic modeling and analysis of hybrid driven multi-link press mechanism considering non-uniform wear clearance of revolute joints," *Meccanica,* 2021, doi: 10.1007/s11012-021-01453-w.