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Case study on fatigue damage due to dynamic effects in a revolute joint with clearance and wear

Manuel Ordiz[1], Javier Cuadrado[2], Mario Cabello[1], Iban Retolaza[1], Daniel Dopico[2]

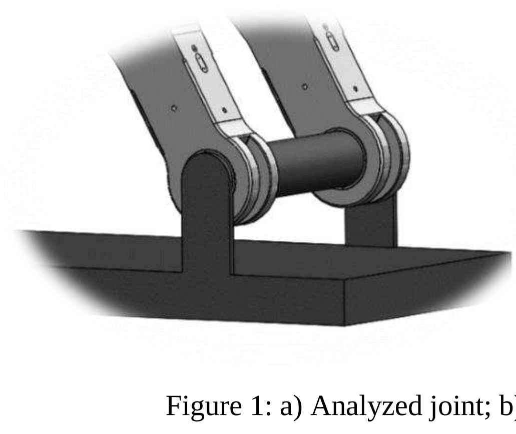
[1] Ikerlan Technology Research Centre, Basque Research and Technology Alliance (BRTA), José María Arizmendiarrieta Pasealekua 2, 20500, Spain
[mordiz, mjcabello, iretolaza]@ikerlan.es

[2] Laboratory of Mechanical Engineering
Dept. of Naval and Industrial Eng.
University of La Coruña
Mendizábal s/n, 15403, Spain
[javier.cuadrado, daniel.dopico]@udc.es

Abstract
Machines are constituted by bodies connected by different types of joints where contact between components occurs, being subject to load and relative motion. This combination of effects produces wear in the bodies at the joint, which in turn yields a change in the dynamics of the joint that expands to the whole mechanism. In this work, the influence of clearance evolution due to wear on the fatigue life of a machine is studied through the multibody-dynamics based analysis of a real case.

Clearances and their effects in machines subject to non-negligible dynamics have been addressed by classical engineering methods for design purposes. On the other hand, the multibody-dynamics community has also carried out some investigations on the topic: an efficient method was developed in [4] to describe the wear evolution in a revolute joint, using as example a three-dimensional mechanism with unbalanced loads; wear in a revolute joint of a slider-crank mechanism was studied by means of RecurDyn in [2], applying a damped contact model from the literature which allowed replicating the results obtained from experiments; a wear model for a revolute joint including a small initial clearance was poposed in [5]. In these works, advanced models were proposed that did not assume that wear occurred in the line connecting the pin and bushing centers. Instead, the exact contact point location was calculated which in turn caused bushing deformation and wear.

However, the described methods suffer from two basic problems: (i) the increment in the size of clearances due to wear that takes place in machines with non-negligible dynamics is not considered in the classical works on fatigue analysis, assuming that clearances are time-invariant; (ii) the proposed advanced wear models are complex, computationally expensive, and difficult to apply within traditional design procedures used in industry.



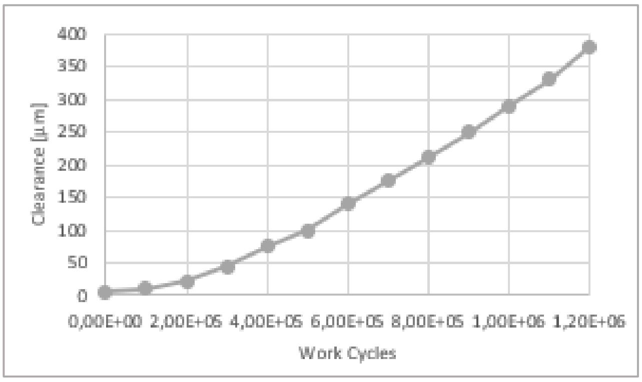


Figure 1: a) Analyzed joint; b) Clearance evolution throughout the cycles.

In this work, seeking to overcome the two mentioned problems, a method based on the wear theory from Archard [1] is proposed for implementation in Simscape. The objective was to create a general model that allowed the calculation of wear and clearance size evolution in any mechanism featuring revolute joints. First, the method was validated by applying it to the mechanism proposed in [5] and comparing the obtained results. The method was then used to estimate the fatigue life of a real industrial press. The mechanism was modeled in Simscape, adding the developed module for wear calculation, and using it to determine the clearance evolution in the critical joint along 1.20E+06 cycles. A maximum wear of 380 µm was obtained after the analyzed period. Figure 1b shows the discrete clearance evolution.

Fatigue life was calculated by coupling the dynamic model for prediction of clearance size evolution in time with a finite-element model developed in ANSYS. In this way, the change in the stresses suffered by the mechanism bodies along the work cycles was obtained.

For fatigue life estimation, the Palmgren-Miner theory for cumulative damage [3] was applied, using the S-N curve corresponding to the material of each body. Table 1 gathers the stresses obtained in a certain body as the clearance size was increasing.

Table 1: Damage including clearance.

Clearance [µm]	Stress [MPa]	Work Cycles	Limit Cycles	Accumulated Damage
10	116	2.00E+05	2.11E+06	0.09
50	122	4.00E+05	8.30E+05	0.24
100	128	6.00E+05	4.80E+05	0.42
175	137	8.00E+05	2.20E+05	0.90
250	150	1.00E+06	7.90E+04	2.54
330	168	1.20E+06	2.20E+04	9.23

Figure 2 compares the results of applying Palmgren-Miner theory to: (i) the case of evolutive clearance, which leads to a life of around 8.00E+05 cycles; (ii) the case of constant clearance, which leads to a life of around 2.11E+06. This demonstrates that including the wear effect in the estimation of fatigue life is relevant and should be considered for the design of a machine with non-negligible dynamics.

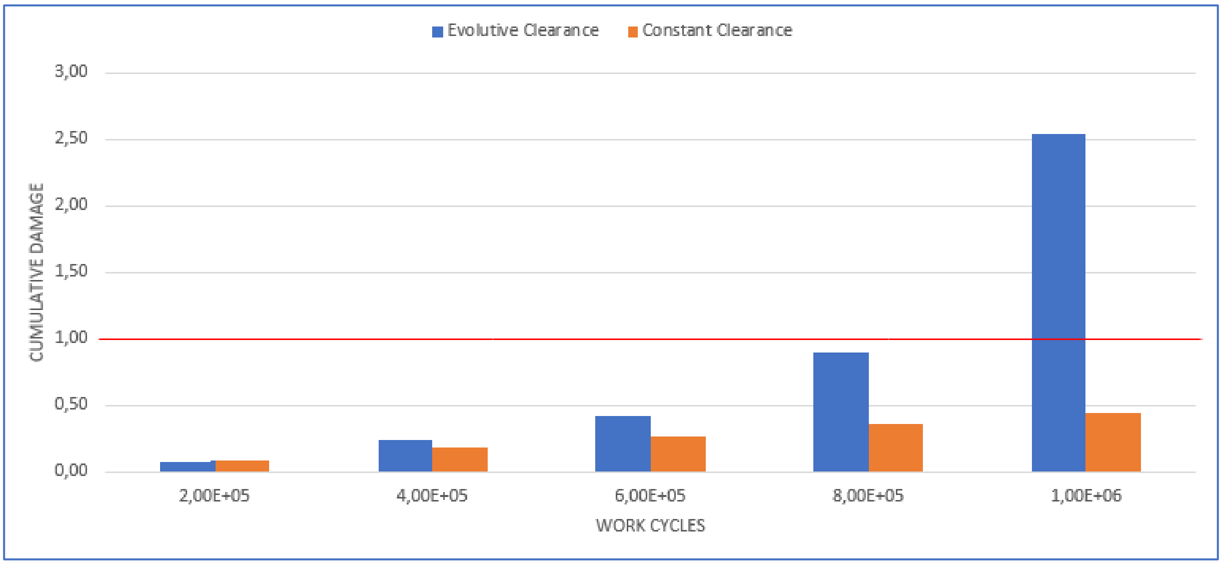


Figure 2: Clearance wear effect in fatigue life.

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