# Dynamic behavior of mechanisms with planar and spatial clearance joints

**Paulo Flores***

*CMEMS-UMinho, Department of Mechanical Engineering, University of Minho, Guimarães, Portugal*

**Abstract**. This study presents a comparative analysis on the dynamic response of mechanisms that include planar and spatial joints with clearance. For that, the fundamental kinematic and dynamic aspects relate to the modeling and simulating joints with dry clearance are analyzed. A compliant approach is used to solve the contact problem at the clearance joints, in which the contact forces are dependent on the local pseudo-penetration and on the contact kinematics. The academic slider-crank mechanism is utilized, as a demonstrative example of application, in order to compare both the planar and spatial formulation for clearance joints and to show the similarities to highlight the differences of such approaches. The overall results presented show that the incorporation of clearance joints in mechanisms significantly influences their response and drastically increases the peaks in reaction moments at the joints. Moreover, the system's response clearly tends to be nonlinear when a clearance joint was included.

## Introduction

Mechanisms, as mechanical systems, are made of several components that can be classified into two groups, that is, bodies and kinematic joints. Usually, the links are modeled as rigid or flexible bodies, while joints are represented by a set of kinematic constraints. The functionality of a mechanical joint relies upon the relative motion allowed between the connected links. This fact implies the existence of a gap, that is, a clearance between the mating parts, and thus surface contact, shock transmission and the development of different regimes of friction, lubrication and wear [1]. The problem of modeling and simulating clearance joints in mechanisms is a quite fertile research area in different fields that has attracted the attention of many authors over the last decades, such as steering suspensions and bushing joints, robotic and parallel manipulators, space deployable systems, ball bearings, and biomechanics [1].
A joint with clearance can be included in a mechanism much like a revolute joint. Figure 1 shows a typical connection with clearance joints found in planar and spatial multibody systems, where the clearance size is strongly exaggerated for illustration purpose only. When there is no lubricant in the joint, contact-impacts events can take place and the corresponding impulsive forces are transmitted throughout the mechanism parts. These impacts can be characterized by a force model, which accounts for the geometrical, kinematical and material characteristics of the joint components. The dynamics of any dry clearance joint is characterized by two different situations. Firstly, when the journal and bearing are not in contact with each other, there are no contact forces associated with the journal-bearing. Secondly, when the contact between the two bodies occurs the contact-impact forces are modeled according to a nonlinear Hertz contact force law together with the Coulomb's friction law [2].

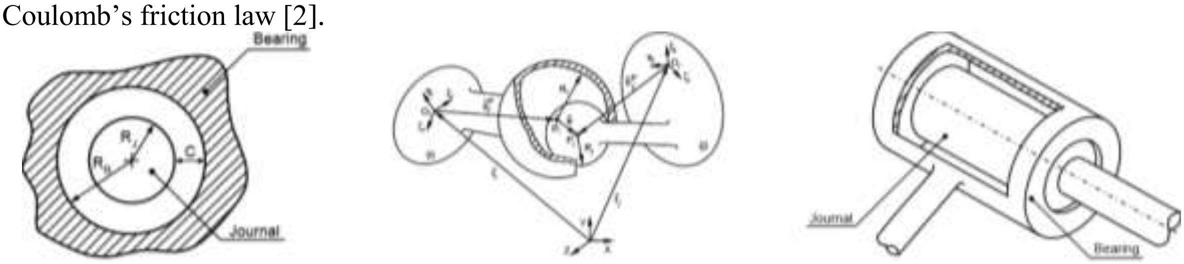


Figure 1: Representation of planar and spatial clearance joints used in mechanisms.

## Results and discussion

In this work a comparative study on multibody systems with 2D and 3D clearance joints is investigated. In this process, the planar revolute joint with clearance, the spherical clearance joint and the 3D revolute joint with clearance have been considered. The overall results presented in this study show that the introduction of clearance joints in spatial multibody mechanical systems significantly influences the prediction of components' position and drastically increases the peaks in acceleration and reaction moments at the joints. Moreover, the system's response clearly tends to be nonlinear when a clearance joint was included. This is a fundamental feature mainly in high speed and precision mechanisms where the accurate predictions are essential for the design of the mechanical systems.

**Acknowledgement**: This work has been supported by FCT with the reference project UIDB/04436/2020.

## References

[1] Tian Q., Flores P., Lankarani H.M. (2018) A comprehensive survey of the analytical, numerical and experimental methodologies for dynamics of multibody mechanical systems with clearance or imperfect joints. *Mechanism and Machine Theory*, 122, 1-57.

[2] Lankarani H.M., Nikravesh P.E. (1990) A contact force model with hysteresis damping for impact analysis of multibody systems. *Journal of Mechanical Design*, 112, 369-376.