

# Multibody Dynamic Modeling and Experimental Characterization of Mechanical Clearance in a Slider–Crank Testbench

**Zeeshan H. Malik, Antonio J. Rodríguez, Emilio Sanjurjo,  
Francisco González, Miguel Á. Naya**

Laboratorio de Ingeniería Mecánica, CITENI, Universidade da Coruña  
Campus Industrial de Ferrol, 15403 Ferrol, Spain

{zeeshan.malik, antonio.rodriguez.gonzalez, emilio.sanjurjo, f.gonzalez, miguel.naya}@udc.es

## Abstract

In mechanical systems, free space at a joint between components, denoted as clearance, is almost always present due to machining tolerances, imperfection, and material deformations. This defect introduces extra, unintentional degrees of freedom in the system, giving rise to strong nonlinear effects in its dynamic behavior, which in turn cause backlash, micro-impacts, vibration, and heat generation. Ultimately, these degrade performance and reliability, and may lead to the malfunction of the machine. Often, wear at the joint interface is the main cause of the development and growth of clearances [1].

Extensive research has been conducted by the multibody system (MBS) dynamics community to understand the causes and effects of mechanical clearance. Work has mainly focused on the forward-dynamics simulation of these systems, which relies on high-fidelity numerical modeling approaches and MBS dynamics formulations. A large number of research contributions focus particularly on revolute joints, although studies on translational clearance exist as well [2], with the slider–crank mechanism serving as a standard benchmark [3]. Several of these studies reported the experimental validation of simulation methodologies as well [4], confirming the difficulty of performing accurate characterization of the impact phenomenon at the joint interface. For a given mechanism and motion, magnitudes like impact intensity and dissipation depend on a series of parameters that determine, e.g., the compliance of the contacting bodies, the friction characteristics at the interface, and internal damping. These are frequently difficult to characterize in practice.

Recently, alternative approaches have been proposed to detect the existence of clearance in mechanical systems and to provide an estimation of the stage of the defect growth. These include the use of parameter-estimation techniques such as Kalman filters [5] and data-driven approaches such as neural networks [6]. Initial results confirm that these methods are able to achieve their goals using synthetic data, but their performance needs to be verified in experimental setups as well. To attain this goal, a slider–crank mechanism with configurable joint and slider clearances, shown in Fig. 1, has been developed as a dedicated testbench.

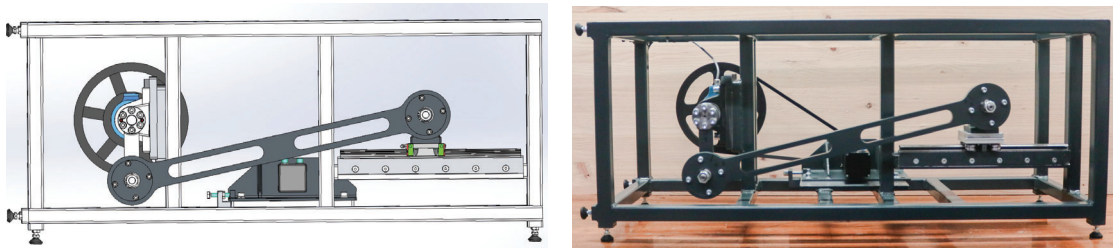


Figure 1: CAD model (left) and experimental setup (right) of the test bench with configurable clearances at the crank-coupler and coupler-slider joints.

Within the framework of a multistage validation strategy for the proposed methods of clearance estimation, the testbench represents an intermediate step between numerical simulation and deployment in industrial environments.

## Test bench design and experimental methodology

The data collected from the test bench will be used to provide an experimental validation of the clearance characterization approaches reported in [5] and [6]. The bench, however, has been conceived with a modular and configurable design so that it can be used in a wider variety of validation experiments. The platform is designed to operate in multiple orientations, with gravity acting along its  $x$ ,  $y$ , and  $z$  axes,

allowing the systematic investigation of gravitational effects on clearance dynamics. Dynamic responses are captured using high-bandwidth accelerometers. The number and location of these can be modified to compare the performance of different sensor configurations. Several clearance radii can be set at the two joints at the end points of the connecting rod, by means of interchangeable joint elements.

Experiments can be conducted under different conditions, varying the above-mentioned configuration parameters, as well as the angular velocity of the motor that actuates the crank. Different approaches to design the optimized experiments will be explored, enabling efficient exploration of the multivariable parameter space while preserving statistical independence between factors.

A first experimental campaign will obtain results under gravity effects along the vertical axis in Fig. 1. These will be used to evaluate the performance of the unscented Kalman filter proposed in [5] and will help to assess the effect of the uncertainty of contact parameters at the joint interface, such as compliance and friction, on the filter predictions. A second round of experiments will focus on providing experimental data to confirm the ability of neural networks to predict clearance size, tested in [6] with synthetic data.

### **Acknowledgment**

The authors acknowledge the support of MICIU/AEI/ 10.13039/501100011033 and ERDF, EU, through project PID2022-139832NB-I00, and grant ED431C 2023/01 from the Government of Galicia.

### **References**

- [1] López-Lombardero, M.; Cuadrado, J.; Cabello, M.; Martínez, F.; Dopico, D.; López-Varela, A.: A Multibody-Dynamics Based Method for the Estimation of Wear Evolution in the Revolute Joints of Mechanisms that Considers Link Flexibility. *Mechanism and Machine Theory*, Vol. 194, art. 105583, 2024.
- [2] Flores, P.; Ambrósio, J.; Claro, J.C.P.; Lankarani, H.M.: Translational Joints with Clearance in Rigid Multibody Systems. *Journal of Computational and Nonlinear Dynamics*, Vol. 3, No. 1, art. 011007, 2008.
- [3] Qiang, T.; Paulo, F.; Lankarani, H.M.: 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*, Vol. 122, pp. 1–57, 2018.
- [4] Flores, P.; Koshy, C.S. ; Lankarani, H.M. ; Ambrósio, J. ; Claro, J.C.P.: Numerical and Experimental Investigation on Multibody Systems with Revolute Clearance Joints *Nonlinear Dynamics*, Vol. 65, No. 4, pp. 383–398, 2011.
- [5] Rodríguez, A.J.; Sanjurjo, E.; López-Lombardero, M; Cabello, M; González, F.; Naya, M.Á.: A Novel Kalman Filter Approach for Clearances Estimation. *12th ECCOMAS Thematic Conference on Multibody Dynamics*, Innsbruck, Austria, Jul. 13–18, 2025.
- [6] Nguyen, V.; Rodríguez, A.J.; Orzechowski, G.; Mikkola, A.; Kim, J.G.; González, F.: Detection of Mechanical Clearances with Data-Driven Approaches. *12th ECCOMAS Thematic Conference on Multibody Dynamics*, Innsbruck, Austria, Jul. 13–18, 2025.