A Novel Kalman Filter Approach for Clearances Estimation

Antonio J. Rodríguez[1], Emilio Sanjurjo[1], Mario López-Lombardero[1,2],
Mario Cabello[2], Francisco González[1], Miguel Ángel Naya[1]

[1] Laboratorio de Ingeniería Mecánica
CITENI, Universidade da Coruña
Campus Industrial, 15403 Ferrol, Spain
f.gonzalez@udc.es, antonio.rodriguez.gonzalez@udc.es,
emilio.sanjurjo@udc.es, miguel.naya@udc.es

[2] IKERLAN
P° J. M. Arizmendiarrieta 2, 20500 Arrasate-Mondragón, Spain
mlopez@ikerlan.es, mjcabello@ikerlan.es

EXTENDED ABSTRACT

1 Introduction

Machinery maintenance is a topic of industrial interest: if a machine starts to malfunction, the whole process might be affected and lead to the interruption of the production. In many cases, malfunctions are related to the presence of wear between moving parts, also known as joint clearance [1, 2]. Clearances also cause additional problems such as noise and vibrations that might decrease product quality and even threaten the safety of the personnel. This issue is usually addressed by programming regular maintenance stops to replace worn out components. Being able to monitor the mechanism behaviour to detect the presence of clearance and observe its evolution is an interesting alternative. Instead of scheduling regular stops, maintenance actions could take place at the time at which they are really necessary, decreasing the downtime of the machinery and avoiding the replacement of components that are still functional. This approach can also provide valuable information to detect the location of mechanical defects. However, this strategy would require more sensors than the ones usually installed in industrial machinery, which are frequently very limited. This poses a practical difficulty to characterize machinery defects during operation.

The information available on a system can be extended by the use of state and parameter estimators, such as Kalman filters. Using a model of the system and a reduced set of sensors, additional data can be estimated to gain more insight into the system. Kalman filters have been combined with multibody models for multiple applications [3]. In [4], the forces derived from the impacts at joints affected by clearance were estimated. This work intends to take a step forward and estimate the size of the clearance, offering more interesting information regarding the evolution of the defect during the operation of the machine.

The mechanism selected as example is a slider-crank linkage (Figure 1). To study the estimation of the radial clearance, a multibody model of the linkage was developed using natural coordinates. A radial clearance of 0.25 mm was introduced at joint A using the contact model presented in [5]. The research was conducted in a simulation environment according to the *three-simulation method* [3]. This method consists in employing three different simulations in order to test the performance of state and parameter estimators: the first is used as the reference or ground truth; the second has some differences or modelling errors with respect to the reference and represents the model of the system; and the third one is the model combined with the Kalman filter, which would correct the errors of the model giving accurate estimations.

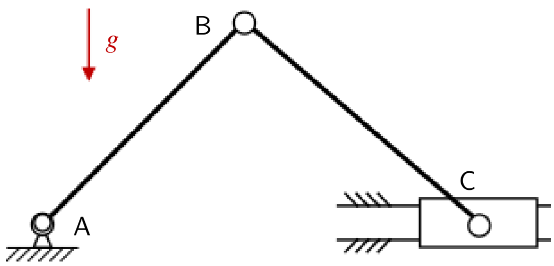

Figure 1: Slider-crank model employed in this work.

Regarding the estimator, there are different versions of the Kalman filter that can be used. In [4], an Extended Kalman filter (EKF) was used for estimating the forces introduced by the clearance. However, a direct relation between the impact forces and the clearance parameters is not easy to find. As an alternative, this work explores the use of an Unscented Kalman filter (UKF). This filter performs the estimations propagating a set of deterministically chosen weighted sample points, known as sigma-points, through the integration of the forward dynamics of the system. In this way, there is no need to mathematically derive the relation between a property of the clearance and the system dynamics.

Following the UKF approach, the state vector considered in this work consists only of the radial clearance in joint A. This results in a total of three sigma-points, which means that three simulations of the slider-crank motion with different radial clearance values must be executed at each time step. From each simulation, the UKF compares the measurements of the reference mechanism with those obtained from each of the sigma-points.

However, in this type of phenomenon, comparing the time-history of variables might not be effective in order to determine the radial clearance. For example, since each sigma-point has a different radial clearance, the time stamp of the impacts is going to be different, even though the macroscopic dynamics might be similar. This problem increases the difficulty of identifying the proper radial clearance over time. On the contrary, studying the frequency spectrum of each sigma-point offers information that can be compared between mechanisms with different clearances. For such purpose, the proposed UKF is modified: each sigma-point is allowed to evolve in time and, after a certain amount of time steps, the fast Fourier transform (FFT) of the crank angular acceleration is obtained for each sigma-point and compared with the FFT of the same magnitude experienced by the ground-truth simulation for that same period of time. Through different metrics, the information of the FFT of the crank acceleration can be turned into valuable information for the UKF.

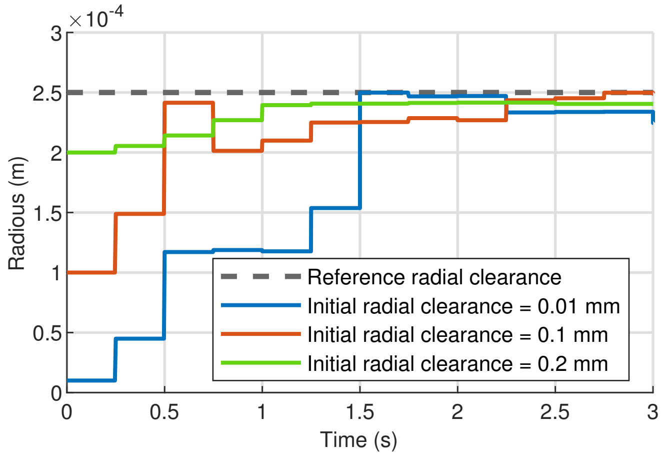

Figure 2: Clearance radius estimation.

As can be seen in Figure 2, the method is able to estimate the radial clearance with independence of the initial guess used for it. For future developments, it is also of interest to extend this method to a more general scenario, where the joint with clearance is unknown, or where different joints are affected by defects.

Acknowledgments

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