Mechanical Clearances Estimation by means of Unscented Kalman Filtering

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Abstract

The performance and life span of industrial machinery is strongly affected by clearances, which develop in the joints that connect the different links of the machine. This defect gives rise to vibration, noise, and heat, causing damages to the machine and even device failure. To prevent damage, conventional approaches rely on scheduled maintenance, detecting and replacing the elements affected by clearance. However, these approaches imply system shutdowns that decrease production throughput. As an alternative, predictive approaches allow one to track the evolution of the defect and schedule maintenance tasks in a way in which components are replaced only when required.

Characterizing clearances in industrial machinery requires a complex instrumentation of the mechanical system under study, which is not always possible to install due to physical constraints or economical reasons. As an alternative, state and parameter estimators, such as the Kalman filter, can be used to gain insight into the state of a mechanical system by combining a simulation model of the system with a reduced set of sensors.

Clearance characterization has been addressed by a large number of publications in the context of multibody system dynamics, e.g., [1, 2]. Including clearances in the simulation of mechanical systems implies the introduction of additional degrees of freedom and the need to detect contacts between the components affected by the defect. Usually, penalty methods are the selected approach to characterize contact dynamics [3]. These methods rely on the knowledge of the physical properties of the contact, such as the parameters that describe stiffness and friction, clearance geometry, and the inertial and flexibility properties of the involved links. In practice, these are often uncertain and sometimes they may vary during operation.

Multibody models have also been combined with Kalman filters to obtain precise estimations of variables and parameters of mechanical systems that cannot be accessed by means of sensors [4]. However, the application of Kalman filters to clearance estimation remains largely unexplored by the multibody community. In previous works, an extended Kalman filter (EKF) was used in [5] to estimate clearance contact forces. Regarding clearance parameters, [6] explored the use of an unscented Kalman filter (UKF) for estimating the radial clearance in an slider-crank mechanism shown in Fig. 1. Based on time-sequences of acceleration data, multiple magnitudes describing the clearance can be derived and used by the UKF to estimate the clearance size.

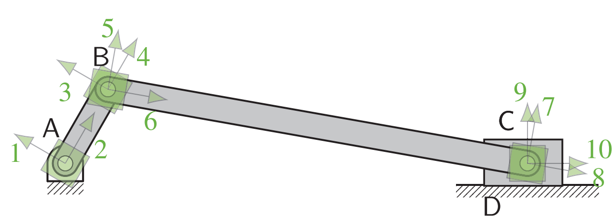

Figure 1: Slider-crank mechanism used in this work and the accelerometers installed.

In [6], only the clearance in the joint A was estimated based on an exponential fit of the Fast Fourier Transform (FFT) of the readings measured by the accelerometers shown in Fig. 1. This work continues this research extending the estimation to different joints and axial clearances, together with the investigation of additional magnitudes for improving clearance estimation and reducing the required amount of sensors. Based on the *three-simulations method* [4], a simulation environment is set to evaluate the performance of the method when estimating the radial clearances in joints A, B and C, and the axial clearance in D by using different magnitudes derived from the measured acceleration sequences, such as the root-mean-square (RMS), Kurtosis, or the previously used exponential fit of the FFT, used as indicators. The manoeuvre consists in a free-falling motion with an initial crank angular velocity of 200 rpms. The total simulated time is of 5 seconds, and the step size for the multibody dynamics Δt_{MBS} is of $1 \cdot 10^{-5}$ seconds, while the estimations of the UKF are preformed with a step size Δt_{UKF} of 0.5 seconds. Preliminary results are shown in Figs. 2 and 3, that confirm that the radial clearance in joints B can be estimated by using either RMS, Kurtosis, or the exponential fit of the FFT. The most accurate results were obtained with the exponential fit. In addition, the method can also provide accurate estimations of axial clearances, as shown in Fig. 3, where the estimations for the axial clearance in joint D are shown.

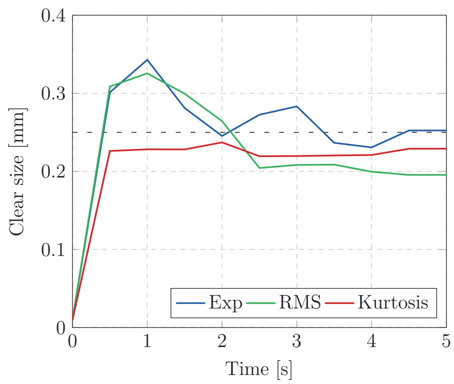

Figure 2: Estimated radial clearance in joint B with different indicators, for a reference radial clearance of 0.25 mm.

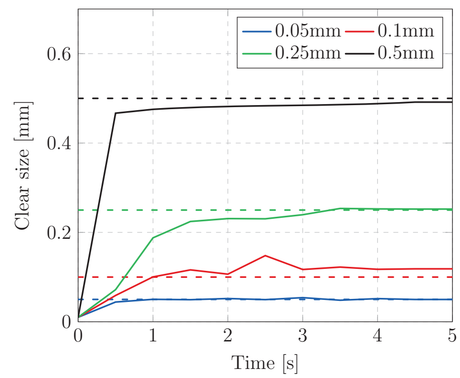

Figure 3: Estimated axial clearance in joint D for different reference values using the exponential fit of the FFT.

Further work will explore the capabilities of the method to detect clearances when their locations are unknown, even in the presence of multiple instances of the defect in the same mechanism, together with experimental validation in a test bench.

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