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Clearance influence analysis on mechanisms

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Abstract

This paper deals with the effects that clearance in the kinematic pairs has on the mechanism configuration. The problem has already been addressed by a number of authors, who have analyzed clearance effects from different perspectives. In this paper, the focus is on a kinematic modelling, assessing the actual configuration of a mechanism with clearance-affected pairs. After the most relevant existing results are briefly reviewed, a new original method to assess clearance influence is presented. The new method is shown to be more flexible and complete than the previous ones: more flexible because it allows the use of a generic model for the kinematic pairs; more complete because it can be used for any mechanism having an arbitrary numbers of links loaded by any set of forces/torques. As a consequence, the method is suitable for evaluating clearance influence in both static and dynamic conditions, when inertial forces/torques acting on each link have to be considered.

Keywords: Clearance; Spatial mechanisms; Open and closed chains; Dynamic and kinetostatic analysis

1. Introduction

Clearance in mechanisms is often a need. Some alternatives to the use of clearance-affected pairs exist, like pre-loaded or elastic pairs. In general, however, the use of such non-conventional pairs in complex mechanisms can become problematic, to the point that clearance-affected pairs

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are used in most applications. Clearance does not have positive effects only: if on the one hand it simplifies the assembling and the manufacturing of the mechanism, on the other hand it generates errors in the pose (position and orientation) of its links. Moreover, it is one of the main causes of shock between the mechanism links, and consequently of vibrations and noise. Evaluating the influence that clearance in the kinematic pairs has on mechanisms is an old problem, and many authors have proposed solutions based on different approaches. Some authors have focussed on the dynamic effects of clearance, both in a theoretical [1–3] and experimental way [4,5]. As a result, they have proposed models that can asses dynamic effects, such as the impacts in the pairs and the consequent vibrations. However, these models are very complex, and spatial mechanisms are hardly studied by this way. Other authors have focussed on a kinematic modelling of mechanisms, trying to asses mainly the positioning accuracy. This last modelling is much easier and intuitive, and it can be very useful for a preliminary evaluation of the mechanism performance. Two main approaches are followed in the kinematic modelling of clearance. The first one can be defined *stochastic*, and expresses the clearance-due displacement through probability density functions [6,7]. The second one can be defined *deterministic*, and tries to exactly determine the displacement of the mechanism links caused by an external load [8–14]. This last approach looks for a more detailed modelling of the physical mechanism, as it tries to exactly describe the occurrence of contact in the pairs. For this reason, such an approach is followed in this paper.

The analysis of several deterministic methods shows that the definition of a mathematical model evaluating clearance influence consists of two main points. First, local models of the mechanism kinematic pairs have to be defined. The local models express the contact conditions and define the relative pose of the pairing elements in each clearance-affected pair. They obviously depend on the kind of pair (revolute, prismatic, etc.) and on its design. Then, after local models have been defined, the kinematic relation between the relative pose of the pairing elements in the clearance-affected joints and the pose error of the mechanism link of interest has to be found. In this paper the two points highlighted above are analyzed separately. For both, the most significant results obtained in previous papers are reported, completed and improved. Eventually, the paper provides a new procedure for the computation of the pose error of the mechanism link of interest for both serial and parallel mechanisms. The proposed procedure is a complete, consistent mathematical tool suitable for evaluating the influence of clearance-affected joints in mechanisms loaded by any distribution of forces/torques on any of its links. Therefore, it can also be used in dynamic conditions, when the inertial forces/torques acting on each link of the mechanism have to be considered. Two examples showing the effectiveness of the method are reported in the last section.

2. Local models

The deterministic analysis of a clearance-affected mechanism in a given configuration requires the knowledge of a local model, that is a kinetostatic model providing the actual relative pose of the pairing elements in each clearance-affected joint. The actual relative pose depends on the constraint reaction the joint transmits. Thus, the first step in order to determine the relative pose of the pairing elements in clearance-affected kinematic pairs is finding the reactions in each pair, that means solving the kinetostatic analysis of the mechanism. After the constraint reactions in each clearance-affected pair have been determined, it is possible to study the behavior of the pair. When