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Kinematic sensitivity analysis of linkage with joint clearance based on transmission quality

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Abstract

This paper presents an effective method to analyze the transmission performance of linkages that have joint clearance. Joint clearance was treated as virtual link to simplify the study. Equivalent kinematical pairs were used to model the motion freedoms caused by the joint clearances. With joint clearance presented, the number of unknown joint parameters is greater than the number of loop closure equations obtained in position analysis. Under kine-static and dynamic analysis, a mechanism should be in equilibrium at any configuration. The joint transmission wrench should equilibrate all externally applied wrenches for each link member. An extra set of constraint equations can be obtained since the joint transmission wrench screw should be reciprocal to the joint twist screw of the member. Then the mechanism positions can be solved with the loop closure and reciprocal equations simultaneously.

Keywords: Joint clearance; Transmission angle; Transmission error; Reciprocal screws

1. Introduction

A single degree of freedom linkage has constrained motion if one input is applied. If joint clearance is significantly large, the motion of the linkage becomes unconstrained. However, when the linkage is driven or exerted by external wrenches, the contact in the joint clearances between two

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pairing members will be confined to a specific position determined by the direction of the resultant of the external forces. The motion will revert to a constrained one. In this paper, the concept of reciprocal screw is used to analyze the transmission performance of linkages with joint clearance.

Every joint must has a joint clearance that may contribute to the positioning error of a linkage. Many investigations have been devoted to the study of joint clearance. One approach used the statistical method, which treats the joint clearance as the dimensional tolerance [1–8]. In fact, the influences of joint clearance to the positioning error are different from link dimensional tolerance. Another investigators considered only a partial set of joint clearance [9–16]. Some papers have considered the effects of all joint clearance [17,18]. Kolhatker and Yajnik [17] calculated the maximum output error due to the clearance. The maximum error occurs when the transmission quality are the worst in a given input range. Ting et al. [18] postulated a geometrical model to explain the output variation in an actual linkage.

When input wrench is applied, the actual joint contact will be forced to a certain position according to the direction of the wrench. It is never to know the maximum error configuration of a linkage before performing force analysis. The output error of the linkage cannot be known, and the transmission quality is also not obtainable. However, the positioning accuracy is important in precision machine design. If actual output error is gotten, the real transmission quality can be evaluated. This investigation presents a directly and effective approach to analyze the position errors of linkages with joint clearances and their effect on transmission performance.

2. Equivalent clearance link

Consider a revolute joint consisting of a pin with radius r_i attached to the ith link that turns in a hole r_j attached to the jth link. It is convenient to assume that the center points of two pairing elements are connected by an equivalent clearance link r so that the analysis based on ideal joints can be applied to the actual joint with clearance [2,18]. As shown in Fig. 1, the r-link is thus the virtual link. It is further assuming that there is always a contact between the pin and hole of the joint under external applied force. The equivalent clearance link will have a length equal to one half of the joint clearance [2].

$$r = \frac{r_j - r_i}{2} \tag{1}$$

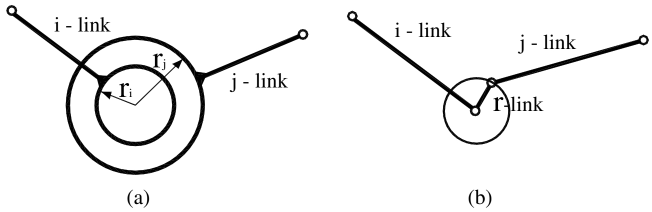

Fig. 1. (a) Joint clearance; (b) Equivalent clearance link r.