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Study of the workspace of a class of universal joints

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ABSTRACT

Universal joint is a key component which has been widely used in industrial field. Study of the workspace of universal joints is very important since the size of their workspace can directly affect workspace of the mechanisms using them. To explore the workspace of universal joints, a mathematical model was developed, by which the workspace of universal joints can be exactly and conveniently calculated based on their geometric parameters. The relationship between the workspace and geometric parameters of universal joints was explored. In the mathematical model, several parameters such as the wing height, the wing width, the cone angle of the workspace and the maximum operating angle of universal joints are defined to depict their workspace profile, the desired workspace of universal joints can be obtained through changing these parameters. A design example is provided to illustrate the design procedures of a universal joint based on the proposed model. The proposed research can help designers in the process of development of universal joints with desired workspace.

1. Introduction

Universal joints are a kind of joints which permit the rod fixed on it to 'bend' in any direction. A universal joint is commonly composed of a pair of hinges located close together, oriented at 90° to each other, connected by a cross shaft. They are widely used in shafts which can transmit rotary motion and torsion. In recent years, universal joints have been employed in parallel manipulators and machine tools as a joint connecting the platform and actuator rod, it has become a key component known as U-joint for the parallel mechanisms.

As we know, the workspace of universal joints is a quite important factor which can directly affect workspace of the mechanisms using them. In general, for a particular kinematics requirement, universal joints used in parallel mechanisms are designed by researchers themselves [1]. However, due to the existence of interference between the two hinge parts, it is difficult to estimate the workspace of universal joints. At one time, researchers merely focused on the maximum operating angle of universal joints and estimated it roughly by visual inspection. However, the maximum operating angle cannot represent the whole workspace of universal joints. In addition, the visual inspection method is either time-consuming or inaccurate. Hence, a new method which can exactly and conveniently calculate the workspace of universal joints is needed.

Until now, a significant body of research has been focused on the kinematics of universal joints with the purpose of solving an inherent problem of universal joints: the output speed is variable although the input drive shaft rotates at a constant speed [2,3]. The variable out speed is harmful for both the universal joints themselves and the mechanisms using them, because it can cause the wear of universal joints and the vibration of mechanisms. Thus, a lot of research has been conducted on the dynamitic stability of the mechanisms or shafts connected by universal joints [4–7], and many new types of universal joints with constant output speed were designed [8]. However, little research has been conducted to analyze the workspace of universal joints and explore

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the relationship between their workspace and geometric parameters. Up to date, the most comprehensive research about the workspace of universal joints was conducted by Hummel and Chassapis (1998, 2000), in their research, the kinematics and dynamics of universal joints are modeled as a spherical four-bar linkage, the geometric parameters of universal joints are optimized by checking the geometric interference between any two components. In their methods, the manufacturing tolerances are considered during the design process, and some useful results are concluded [9,10]. However, their research mainly focuses on the optimization design of a class of universal joints considering interference, load and manufacturing tolerances, while the whole workspace of universal joints and the effects of geometric parameters on it were not discussed. In recent years, some research was found on the investigation of interference of universal joints designed for parallel mechanisms [11,12], however, their research only focuses on the interference judgment of universal joints and the workspace of mechanisms using them.

Unlike prior research, in the present study, the interference relations between the two hinges of a universal joint were investigated from a geometric view. A mathematical model was developed to calculate the interference curves and workspace of a universal joint, by which, the angle between two rods fixing on the bottom hinge and upper hinge can be calculated. Also, the effects of geometric parameters on the workspace size and profile of universal joints were explored. A design example is provided to illustrate the design procedures of a universal joint based on the provided model. The proposed model has the capability of capturing the dominant parameters influencing the workspace of universal joints. It can help designers in designing the universal joint with desired workspace.

2. Interference curve between two independent rotation angles

Take a universal joint as research object, the universal joint and its geometric parameters are shown in Fig. 1.

For simplification, the universal joint investigated in this paper fulfills the following limitations:

$$\sqrt{a_1^2 + b^2} < h_2 < h_1, \quad b < a_2 < a_1. \tag{1}$$

The limitations presented above can ensure that the universal joint rotate beyond 90° in both independent rotation directions. In general, most of universal joints fulfill the limitations, universal joints beyond the limitations are not discussed in this paper.

For easy description, three coordinate systems $o - xyz$, $o' - x'y'z'$ and $o'' - x''y''z''$ attached to the bottom hinge, cross shaft and upper hinge of the universal joint respectively are established, the origins of the three coordinate systems overlap together, and each coordinate system can move correspondingly with the movement of those components. Defining the rotation angle of the cross shaft with respect to the bottom hinge as α and the upper hinge relative to the cross shaft as β, the angles α and β are the two independent rotation angles of the universal joint, they represent the two independent rotation degrees of freedom (DOFs) of the universal joint.

For convenience, some notations are defined to illustrate the structural features of the universal joint, which are shown in Fig. 2.

In this research, to illustrate the interference relation between two hinges of the universal joint, an interference curve of two independent rotation angles is derived. Due to the structural symmetry of the universal joint, the interference curve of two independent rotation angles can be divided into four symmetric sections. Hence, as long as one section of the interference curve is determined, the whole interference curve of two independent rotation angles will be obtained. Actually, the space enclosed by the whole interference curve is the space where interference between two hinges of the universal joint does not occur. In each section, the interference curve is divided into five segments by six characteristic poses of the universal joint, the six characteristic poses of the universal joint are shown in Fig. 3. Each segment of the interference curve denotes a continuous motion state of the universal joint.

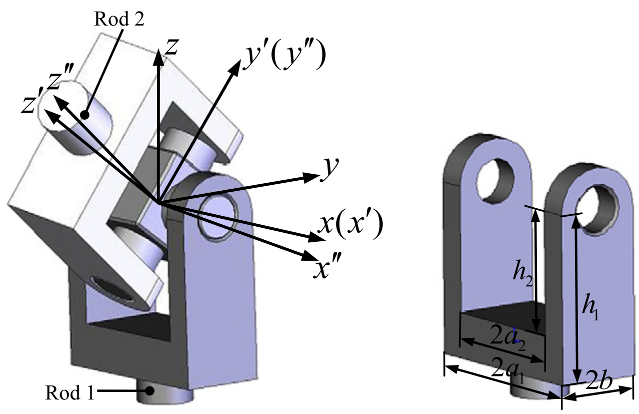

Fig. 1. 3D model of universal joints and its geometric parameters.