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Research paper

Type synthesis and analysis of parallel mechanisms with sub-closed-loops

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ABSTRACT

For the special needs of attitude adjustment and vibration isolation of precise instruments, parallel mechanisms with sub-closed-loops (PMWS) are proposed to eliminate the interferences that vary in frequency. First, the multi-drive units composed by sub-closed-loops are synthesized by two derivative methods, and the PMWS with diffident DOF are synthesized based on screw theory. Furthermore, proposing the concept of the sub generalized coordinate, and the first and the second order influence coefficients of each link of PMWS are established under the generalized coordinates and the sub generalized coordinates. Besides, based on the principle of virtual power and the Newton-Euler formula, meanwhile combining the kinematics analysis of PMWS, the dynamics formulas of PMWS are established separately in joint space and operational space. Finally, taking 6-(PRRR)US PMWS as numerical example, by comparing the results of theoretical calculation and simulation, the kinematics and dynamics formulas of PMWS are verified.

1. Introduction

In order to ensure the stable working environment of the precise instruments installed on satellites, ships or vehicles, it is necessary to eliminate the interference caused by the surrounding environment. The interference can be divided into two forms, one form is the low frequency and high amplitude attitude interference; the other form is high frequency and low amplitude vibration interference. Therefore, an interference compensation mechanism is needed to realize the motions of attitude adjustment and vibration isolation.

At present, there are mainly three kinds of methods to realize the mixed motion. The first method is relying on the strong performance of the single drive, which generally works in the specific frequency and amplitude ranges, but it may cause damage to the instruments if the frequency and amplitude ranges are beyond of reach, so this method is not very feasible [1–4]. The second method is connecting two layer mechanisms in series, and the first layer is for realizing the attitude adjustment, the second layer is for realizing the vibration control. This method is mainly used in vehicle motion simulation, which is generally for the single axis vibration control, and this kind of equipment occupy relatively large space [5–13]. The third method is using the parallel mechanisms with sub-closed-loops (PMWS), and this method can effectively realize attitude adjustment and vibration isolation by the multi-drive unit, which is in the form of sub-closed-loop [14–18].

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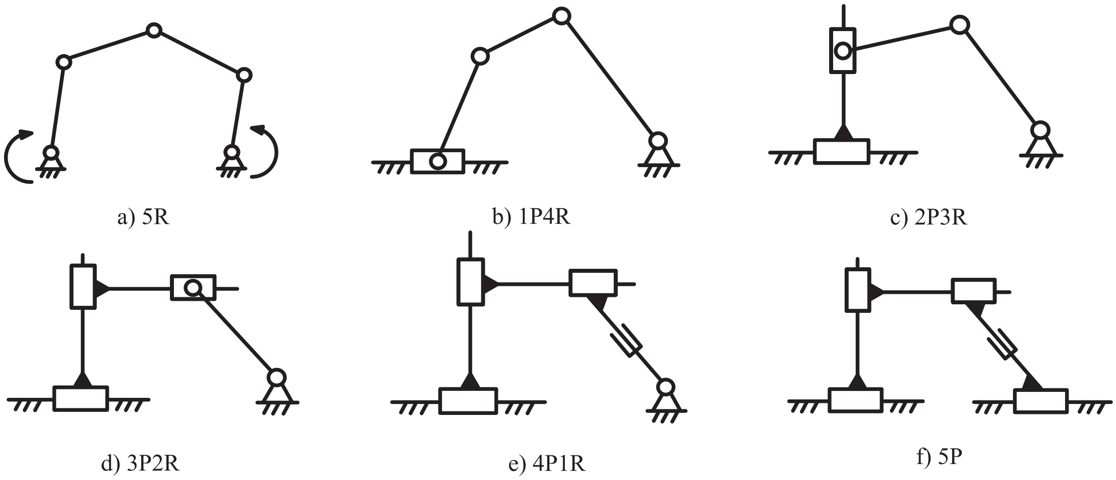

Fig. 1. Types of planar five-link linkage.

However, the relative motions of the sub-closed-loop links are generally nonlinear, which makes it difficult to analyze the kinematics and dynamics of the parallel mechanism with sub-closed-loops (PMWS) [19,20]. The synthesis methods and kinematic characteristics of the closed-loop mechanism are studied in the literature [21,22]. In literature [23–26],Lie group and finite screw theory are selected to carry out the synthesis of various types lower-mobility parallel mechanism. Y. Fang. etc. [27–29], based on the synthesis of sub-closed-loops, synthesize a class of metamorphic mechanisms. A class of six DOF PMWS with various forms is designed. At the same time, the PMWS are belonged to the kinematically redundant parallel mechanisms, and classes of parallel manipulators with kinematic redundancy are synthesized in literature [30–33].But the above studies only analyze the degree of freedom and the kinematic attitude mapping solution, ignoring the mapping relation of the velocity and acceleration between the links and the generalized input, which limits the transformation to reality, because the influence coefficient of the mechanism directly reflects the force and power of the drives. This concept was first proposed by Tesar [34,35], and the influence coefficients of series mechanisms are obtained. Based on the influence coefficient of series mechanisms, Z. Huang. etc. [36–38] established the influence coefficient of the parallel mechanism by the screw theory. In the existing literatures [39–41], the influence coefficients were mostly for the parallel mechanism without sub-closed-loops, and there are no basic formulas for the PMWS. The analysis of this kind of mechanism is mainly based on the direct derivation of the attitude vector, or according to the particularity of the sub-closed-loop to find equivalent virtual link, then solve it by the general method. J. Gallardo-Alvarado and J.M. Rico-Martinez first introduced the Jerk Influence Coefficients to solve the closed chains with multiple-DOF [42,43], and all the kinematics analyses of PMWS are based on it. Zhang [44] used screw theory to analyze the kinematics of PMWS, but the mapping of acceleration is not obtained. On the basis of the above, the PMWS are synthesized by two kind of derivation methods and screw theory, and the formulas of kinematics and dynamics of PMWS are established by using screw theory in this paper.

The paper is organized as follows. In Section 2, the multi-drive units in the form of sub-closed-loop are synthesized. In Section 3, PMWS with diffident DOF are synthesized based on screw theory. In Section 4 and Section 5, kinematics models and dynamics formulas of PMWS are established. In Section 6, taking 6-(PRRR)US PMWS as numerical example, the theoretical models are verified by the simulation. In Section 7, draw the conclusions.

2. Synthesis of multi-drive units

Generally, the multi-drive units are in the form of the sub-closed-loops, which can be divided into planar sub-closed-loop and spatial sub-closed-loop. In contrast, the planar sub-closed-loop unit can avoid its singular configuration more easily, so this paper analyzes the multi-drive units which are in the form of planar sub-closed-loop.

2.1. Synthesis of double-drive units

The double-drive unit requires two degrees of freedom, and the planar five-link linkage accords with this point. According to the types of kinematic joints, the planar five link linkage can be divided into 5 major types, namely 5R, 1P4R, 2P3R, 3P2R and 4P1R, as shown in Fig. 1. The order of 5P linkage is 2, but its degrees of freedom are 3, so it cannot be used as a double-drive unit [45].

According to the different connection sequences of the kinematic joints, each type can be divided into different sub configurations as follows.

Type 5R: only 1 configuration, RRRRR, as shown in Fig. 1(a).

Type 1P4R: 3 configurations, PRRRR, RPRRR and RRPRR, as shown in Fig. 2.