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Mobility variation of a family of metamorphic parallel mechanisms with reconfigurable hybrid limbs

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ABSTRACT

This paper presents a planar metamorphic mechanism (PMM) which has three distinct working phases and a family of metamorphic parallel mechanisms with a PMM as closed-loop subchain in each limb. The study starts from analysis of mobility variation and motion characteristics in each phase of the PMM based on screw theory. Three types of reconfigurable hybrid limbs are then constructed by integrating the PMM and serial chains capable of supplying one constraint force and one constraint couple. This leads to the design of a new family of metamorphic parallel mechanisms in which the platform is connected to the base by three reconfigurable hybrid limbs. The configuration changes of the reconfigurable limb associate with the three distinct phases of the PMM are analyzed and the constraints exerted by the reconfigurable limb in various configurations are identified. The analyses reveal that the metamorphic parallel mechanisms have ability to alter the performance of platform from full 6-DOF configuration to 5-, 4- and 3-DOF configurations resorting to the internal configuration variation of the three reconfigurable limbs. Finally, actuation models with selected joints for mounting drives for the metamorphic parallel mechanisms are addressed and application cases including the potential for hybrid additive and subtractive manufacturing machine of the proposed mechanisms are discussed in details.

1. Introduction

With the rapid development of science and technology, robots and mechanisms with changeable structures and mobility are expected in production to accommodate different operation environments and meet various task requirements. Several kinds of reconfigurable mechanisms such as the kinematotropic linkages [1,2] and metamorphic mechanisms [3,4] have been developed in the past decades.

Metamorphic mechanisms are a kind of mechanical assemblies with changeable mobility resorting to their structure variations. Since the proposal in 1998 [5], the metamorphic mechanisms have drawn more and more attentions in the field of mechanisms and robotics. Parise et al. [6] developed ortho-planar metamorphic mechanisms which can change their topological structures in two orthogonal planes. Chen et al. [7] proposed a metamorphic underwater vehicle that can change the shape of its body continuously in accordance with the microorganism. Liu and Yang [8] investigated the essence and characteristics of metamorphic mechanisms and presented three metamorphic ways for the topological structure changes of metamorphic mechanisms. Dai and Jones [9] introduced matrix representation for changing the topological structures of metamorphic mechanisms. Wang and Dai [10] presented an metamorphic equation for representing the configuration change of metamorphic mechanisms. Dai et al. [11,12] presented a novel multi-fingered robotic hand in which a five-bar spherical linkage is used as metamorphic palm. Li et al. [13] developed a systematic methodology for the structure synthesis of metamorphic mechanisms based on augmented Assur groups. Valsamos et al. [14] proposed an approach to determine the best anatomy of a metamorphic serial linkage for a given task.

Though the metamorphic mechanisms have been extensively studied, relative few metamorphic parallel mechanisms with ability either to alter motion mode or to perform mobility change were presented [15]. Zhang et al. [16,17] proposed a vA joint which has three mobility phases and integrated the vA joint in the construction of several metamorphic parallel mechanisms. Gan et al. [18–21] presented a new joint coined as rT joint and put forward a general procedure for mobility-change-aimed metamorphic parallel mechanism construction. Carbonari et al.

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[22–25] designed a lockable universal joint and developed a class of metamorphic parallel mechanisms which can be used in many applications such as in quality control or haptic interface. Apart from the metamorphic parallel mechanisms, the kinematotropic parallel mechanisms, which also constitute an important class of reconfigurable parallel mechanisms, have attracted certain attentions in the research community. Several kinematotropic parallel mechanisms which employ the constraint singularities either among the serial limbs [26–29], or inside the hybrid limbs due to the existence of kinematotropic closed-loop chains [30], have been proposed. It should be noticed that in order to keep favorable dynamic performance, the actuation scheme of reconfigurable mechanisms with parallel structures should be taken into consideration in the design stage.

In this paper, a planar metamorphic mechanism (PMM) with three distinct phases is presented and then integrated in the construction of three types of reconfigurable limbs leading to a new family of metamorphic parallel mechanisms. The wide range mobility variations of the proposed metamorphic parallel mechanisms are addressed and the superior actuation schemes for the mechanisms are demonstrated. This paper is arranged as follows: Section 2 puts forward the planar metamorphic mechanism and its phase change. A new family of metamorphic parallel mechanisms and their basic characteristics are presented in Section 3. In Section 4, topological configurations and constraints of the $R_1PR_1R_2$-PMM reconfigurable limb are analyzed. Mobility variations of the $3R_1PR_1R_2$-PMM parallel mechanism are demonstrated in Section 5. Sections 6, 7 and 8 analyze the actuation scheme and discuss the singularities and potential applications of the proposed mechanisms. Finally, conclusions are drawn.

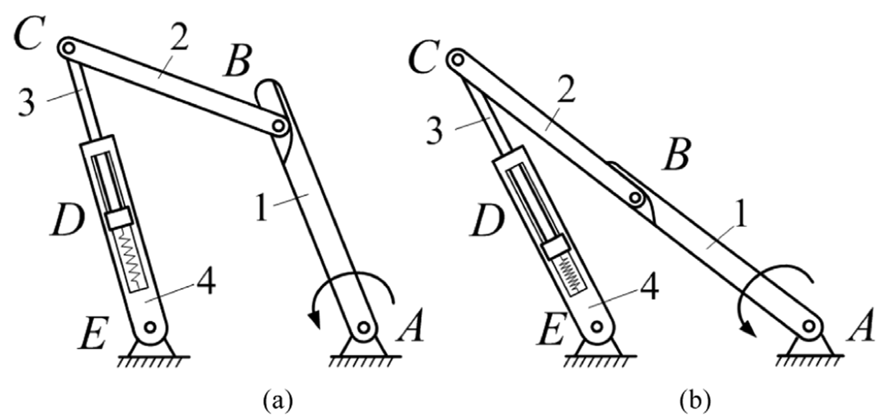

Fig. 1. Two phases of the single driven planar metamorphic mechanism (a) planar four bar linkage phase; and (b) crank-slider phase.

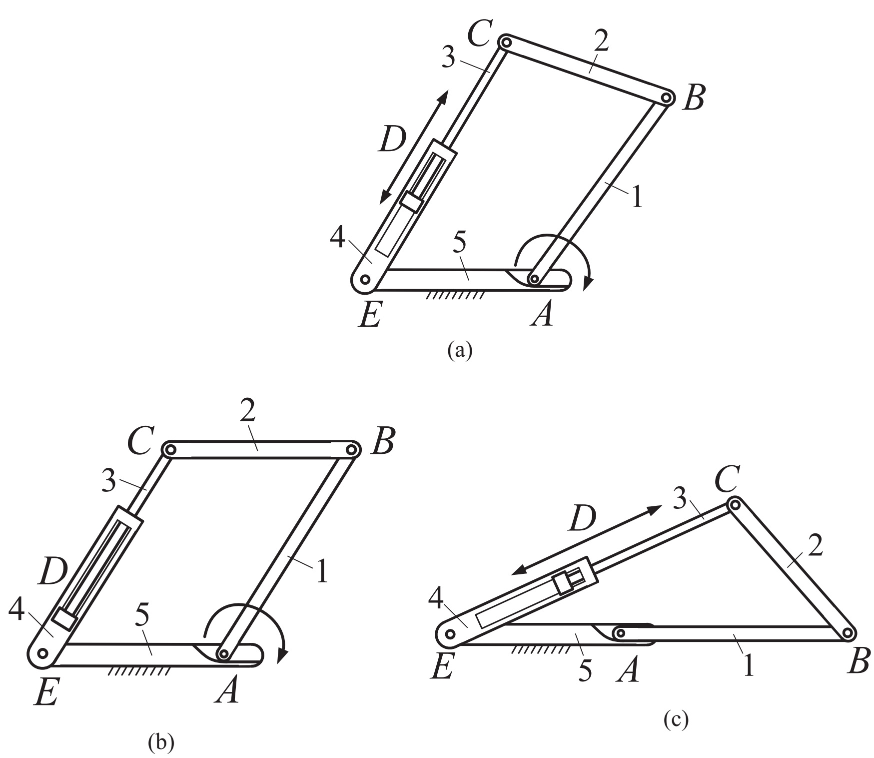

Fig. 2. Three phases of the PMM (a) source phase; (b) P phase; (c) R phase.