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Original Research Article

General method of structural synthesis of parallel mechanisms

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ABSTRACT

This paper presents a method of the structural synthesis of spatial or planar parallel mechanisms. The method exploits the combined strengths of the Baranov method and the intermediate chain method. It makes possible to create complete sets of parallel mechanism solutions. Relations for the number and structure of branches are provided. The successive steps in the procedure for generating a structural form of a closed branch, the opening of the branch, the way of constructing a parallel mechanism from branches with negative and zero degree of freedom (DoF) and the connection of the drives separated from the branches are described.

The proposed method of structural synthesis was applied to generate a complete set of branch solutions, written using numerals representing the number of links in a branch and the number of kinematic pairs of proper class, and to demonstrate the possibilities of creating mechanisms with a different number of branches. The end result was a complete set of possible spatial parallel mechanism solutions for the required mobility.

1. Introduction

Parallel mechanisms with a multibranch (also called multileg or multilimb) connection between the platform (driven link) and the base are most often used in manufacturing machines [8,26,32,39]. The working tool (a milling cutter, an abrasive disc, etc.) is equipped with its own drive and is usually mounted on a platform. The guidance of the tool (the platform) by a parallel mechanism increases system stiffness whereby considerable working loads can be carried, high tool position repeatability is ensured and the system overall dimensions and mass can be reduced. Parallel mechanisms are also widely used as positioning devices, motion simulators and assembly manipulators [4,26,27,32,39]. The drawbacks of parallel mechanisms are their relatively small work zone and the possible occurrence of singular positions [10,11,14,26,32].

The design of parallel mechanisms' structures is generally based on the designer's experience, his/her intuition, accidental ideas or the adaptation of well-known and well-tried solutions. As a result, the same structures tend to be repeated, with the particular designs differing in mainly their mobility – degree of freedom (DoF), geometry (the mutual location of the

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kinematic pairs, the shape of the members, etc.) and the type of drives used [18,26,31,32].

The aim of this research was to develop a general method of the structural synthesis of spatial parallel mechanisms and apply it to create a complete set of feasible and technically viable structural designs of such mechanisms.

2. Method of structural synthesis of parallel mechanisms

Parallel mechanisms are characterized by a multibranch connection between the platform and the base or between the moving links and the base [5,8,26,32,36,39]. If all the branches are identical, the mechanisms are referred to as symmetric, otherwise as asymmetric. Many works, based on different approaches, are devoted to the research on the structure of parallel mechanisms.

Early research on parallel mechanisms concentrated on synthesis of the six degrees of freedom Stewart-Gough-type platform with six branches. In the last 25 years the type synthesis of parallel mechanisms with fewer than six degrees of freedom have attracted the researchers' attention [18,32].

In 2002 Merlet in [33] has stated: "Synthesis of parallel robot is an open field . . . and, in my opinion, one of the main issues for the development of parallel robots in practice" indicating the direction of further research on designing parallel mechanisms.

Kong in 2003 in [28] and Gogu in 2008 in the book [18] made a review of the applied methods of the parallel mechanisms' structural synthesis. The approaches to the synthesis can be divided into couple main groups: the approach based on the screw theory, the approach based on the displacement group theory, the approaches based on kinematics and mobility criterion. Gogu added to the existing synthesis methods an approach based on the theory of linear transformations.

The general approach to structural synthesis of parallel mechanisms, generating a specified motion pattern, based on the screw theory were proposed by Kong in [28] and by Gosselin in [29]. Equally numerous works on the structure of parallel systems deal with methods based on the screw algebra, e.g. papers by Hunt [24], Tsai [16], Carricato [13].

Methods based on the displacement group theory applied to the synthesis of parallel mechanisms are discussed by Herve [21–23], Li et al. [30], Karouia [25]. Generally, these methods are the most appropriate for the structural synthesis of parallel mechanisms with a predetermined motion pattern.

Methods based on the theory of linear transformations and evolutionary morphology presented by Gogu [17,18] enable obtaining, in a systematic way, the structural solutions of the parallel mechanism with two to six degrees of freedom.

Structural synthesis methods are often based on analysis of the degrees of freedom (mobility criterion) of the whole mechanism or its particular branches and have been discussed in the last 15 years inter alia by Bałchanowski [3–5,9], Romaniak [36,37], Alizade [1] and Rasim [38]. Methods of synthesis based on the graph theory are described among others by Ding in [15].

A complex method based on the Baranov method [12] and the intermediate chain method [34,35] for the structural synthesis of parallel mechanisms is developed in this paper. The basics of this method have been developed by the author and presented in [6] and [7]. An important problem not addressed by the latter two methods is the determination of the number of branches connecting the platform with the drivers and the base. Exploiting the strengths of the two methods the new method of the structural synthesis of parallel mechanisms provides an answer to the question concerning the number of branches and their structure and thereby makes the structural synthesis of parallel mechanisms possible. The proposed method is more universal and remedies the deficiencies and inconveniences of the previous methods.

2.1. Determination of number of branches

The number of branches is interrelated not only with mobility (DoF) M_t of the mechanism being designed, but also with the type and number n_c of drivers fixed in the base, number f_{1c} of actuated pairs and number n_s of variable-length links (linear actuators) which may occur in the intermediate chain connecting the platform with the base and even with a driver. Using the intermediate chain method [34,35] one can find that each mechanism consists of base 0, platform p with DoF M_p, a driver or drivers n_c with DoF M_c and chain U of intermediate links (Fig. 1) with DoF M_U. Under this assumption the mobility of a mechanism can be expressed as follows:

$$M_t = M_c + M_p + M_U \quad (1)$$

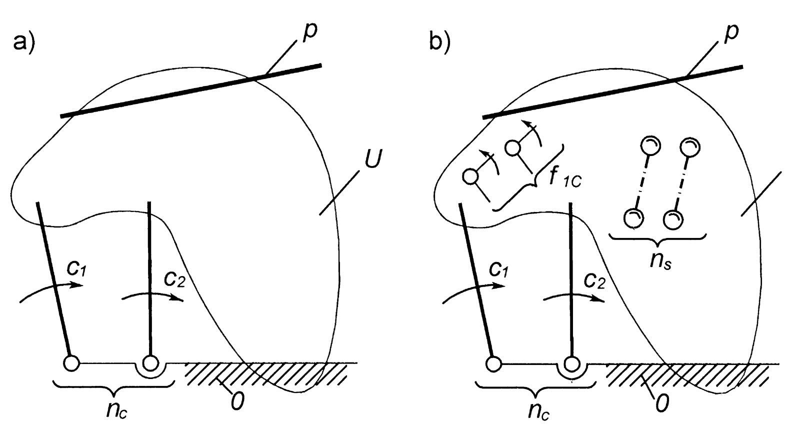

Fig. 1 – Assumptions for intermediate chain method – division of mechanism into platform *p*, base 0 and drivers-at-base n_c: (a) empty chain *U*, (b) chain comprising actuated pairs f_{1c} and variable-length link n_s.