Mechanism and Machine Theory 108 (2017) 57–74

Contents lists available at ScienceDirect

Mechanism and Machine Theory

journal homepage: www.elsevier.com/locate/mechmachtheory

Constant motion/force transmission analysis and synthesis of a class of translational parallel mechanisms

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ARTICLE INFO

Keywords:
Screw theory
Motion/force transmission
Translational parallel mechanism
Transmission power
Type synthesis

ABSTRACT

Motion/force transmission is one of the most important issues and the foundation of analysis and optimal design in the field of parallel mechanisms. It reflects the capacity that each limb in a parallel mechanism transmits its driving force to the moving platform and also the output capacity of the moving platform under definite input of the limb. Several performance indices were proposed to measure motion/force transmission. However, they are instantaneous values varying with different poses. In this paper, a criterion for constant power transmission and the excellent motion/force transmission occurring within a class of translational parallel mechanisms in different poses is proposed based on screw theory. To obtain the translational parallel mechanisms with constant and excellent motion/force transmission, a host of configurations are synthesized based on constraint screw theory when the criterion is met. The criterion proposed in this paper is expected to be applied for the translational parallel mechanisms to analyzing motion/force transmission and optimizing the design.

1. Introduction

Parallel mechanism is widely used for its high accuracy, compacted structure, large load to weight ratio and excellent carrying capacity. Performance evaluation is attracting an increasing amount of efforts nowadays. A practical evaluation index is of great importance in introduction of type synthesis and dimension optimization. The design of 3-degree of freedom(DOF) parallel mechanisms can be based on a multitude of criteria, i.e., workspace [1,2], dexterity [3–5] singularity avoidance [6],stiffness [7], dynamics [8], and so on. Motion/force transmission reflects the capacity that each limb in a parallel mechanism transmits its driving force to the moving platform and also the output capacity of the moving platform under definite input of the limb. Scholars have had a host of research achievements on this issue. The transmission angle was introduced by Alt [9]. Hain [10] applied it to planar mechanisms. The conclusion that the force transmission was better, as the angle increased was obtained. Dresner et al. [11] and Bawab et al. [12] applied the transmission angle in linkage synthesis problems. The virtual coefficient, introduced by Ball [13,14], was used as a transmission factor by Yuan et al. for spatial mechanisms [15], where the value of this factor varies from −1 to +1. Wu et al. [16] adopted the virtual coefficient based upon indices to the evaluation of the transmission quality and the optimal design of the asymmetrical spherical parallel mechanism. Sutherland and Roth [17] advocated the transmission index (TI) for the first time, a normalized form of the transmission factor, which is dependent only on the geometric properties of the linkage. Nevertheless, the value of TI they got was a local maximum one, which could not reflect the real transmission capacity of a

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http://dx.doi.org/10.1016/j.mechmachtheory.2016.10.008
Received 25 April 2016; Received in revised form 12 October 2016; Accepted 14 October 2016
0094-114X/

mechanism. Then Chen and Angeles [18] further proposed a generalized transmission index (GTI) that is applicable to single-loop spatial linkages with fixed output and single or multiple DOFs. Wang [19] analyzed the singularity by using the GTI and presented the workspace of mechanism with good value of transmission index. Afterwards, Chen [20] proposed the method systematically for calculating the maximum value of the transmission power in whole feasible poses. Wu [21] proceed the optimal design of spherical 5R parallel mechanisms by taking into account the motion/force transmission. More recent studies to identify singularity and closeness to singularity had also been reported via transmission analysis [22,23].

As is well known, transmission power reflects the transmission capacity of forces and motions from the input to the output. The reciprocal product between a twist screw and a wrench screw of a configuration-dependent limb is defined as the instantaneous transmission power. In general, the transmission power varies with poses. Consequently, the ratio of the transmission power in an arbitrary pose to the potential maximum one in the whole operating workspace is defined as a measure of transmissibility performance evaluation. The bigger the ratio is, the higher the level of a mechanism exerting its good transmission performance will be. Liu [22] advocated the input transmission index (ITI), output transmission index (OTI) and constraint transmission index (CTI). These three performance indices based on the transmission power are frame invariant with a range between zero and unity and measure the closeness to singularity. Based on the comprehensive analysis of previous studies, Marlow et al. [24] summarized three singularities. The respective performance indices based on the power coefficient are input transmission singularity (ITS), output transmission singularity and constraint transmission singularity (CTS). They are frame invariant with a range between zero and unity and were proposed to measure the closeness to singular positions. A unity value signifies the optimal transmission of motion/force from the unit wrench to the related unit twist, while zero occurs when the unit wrench can no longer transmit any motion/force to the related twist. Actually, it is indefinite to evaluate the transmission quality of a limb merely on the basis of the value of its transmission power taking no account of its dimension. The literatures [21,25–27] made dimensional optimization for mechanisms based on motion/force transmission performance evaluation. Most analysis methods and indices to evaluate the transmission quality of mechanisms invariably are instantaneous values varying with different poses as well as based on dimension. However, Kong and Gosselin [28] proposed the first globally isotropic 3-CRR translational parallel manipulator which is just to guarantee the geometric condition and has nothing to do with dimension. The literature motivates us to further study that whether there exists a class of mechanisms, which can keep constant power transmission just because of their configurations if we merely account for transmission performance instead of dimension synthesis. In this paper, a criterion for constant power transmission and the motion/force transmission being excellent occurring within a class of translational parallel mechanisms in different poses is proposed based on screw theory. A host of configurations are synthesized based on constraint screw theory when the criterion is met. The criterion proposed here is expected for the translational parallel mechanisms to analyze motion/force transmission and optimize the design.

The reminder of this paper is organized as follows. The next section gives a brief introduction concerning the constraint wrench screw (CWS), transmission wrench screw (TWS), output twist screw (OTS) and transmission power of limbs. A criterion that the translational parallel mechanisms can achieve constant power transmission and the motion/force transmission is excellent in different poses is proposed. In Section 3, a class of 3-DOF translational parallel mechanisms with these characteristics is synthesized based on constraint screw theory when the criterion is met. To verify validity of the criterion, Sections 4 and 5 present the motion/force transmission performance analysis of 3-CRU and 3-PRRU (C,R,U and P stand for cylindric, revolute, universal and prismatic joint, respectively) translational parallel mechanisms, respectively. Meanwhile, the "original" input power is introduced and the angle between the axial directions of the TWS and MTS which exactly reflects the capacity of the "original" input to output

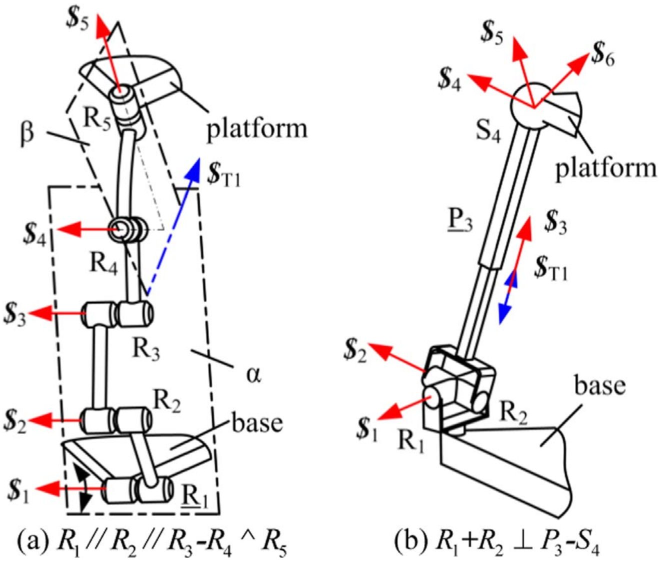

Fig. 1. The analysis of the TWS.