

Preface

Linkages are widely used in our life and work. Almost all planar linkages can be decomposed with a number of equivalent four-bar linkages which are considered to be one of the fundamental mechanism forms. As the simplest closed chain mechanism, planar four-bar linkages are extensively used from mechanical engineering to aerospace engineering and even civil engineering.

This book focuses on the design of a kind of special planar linkages which consist of a number of pivot jointed scissorlike elements (SLEs) in one or more different planes. These planar linkages are overconstrained in structure but allow to stretch or compact in some directions; therefore, they have the advantages of both truss and mechanism. However, the kinetostatics and dynamics of these linkages are different from their existing counterparts of trusses or mechanisms. The statics, kinematics, and dynamics of such planar linkages are important topics in applications. We sincerely hope the book will be beneficial for mechanical engineers, robot design engineers, and researchers in other related fields.

Chapter 1 presents an overview of the pivot jointed planar linkages that will be investigated in this book. Some definitions, such as planar kinematic chain, mobility, planar linkages, workspace and singularity, design problems including statics design, kinematics design, and structural dynamics of planar linkages, are discussed in this chapter.

Chapter 2 develops a uniform position design equation for planar four-bar linkages. According to Burmester theory, a general planar four-bar linkage could trace five arbitrary accurate positions at most. However, modern design often requires a mechanism to precisely or approximately trace more positions. The text starts from proposing a uniform equation for position design and then provides a proof for the sufficiency and necessity. The algorithm can search the accurate results when there are such solutions for the specified n precise positions; otherwise, the best approximate solutions will be found. This permits the engineers to directly obtain the planar four-bar linkages when the specified positions are prescribed.

Chapter 3 proposes a foldable stair which remains the walking conversions of human being and all advantages of concrete stair in civil engineering. The stair is discussed as a mechanism synthesis example with screw theory in accordance to

the common concrete stairs between two floors. It consists of a number of identical deployable SLEs that form the staircases when expanded. The instantaneous screw of every stair represents the relative rotation and the rotation center of the stair. The actuator is a planar four-bar linkage which is synthesized in line with the two extreme positions of the stair, folded and unfolded.

Chapter 4 starts from the discussion of the number of points that a planar four-bar linkage could precisely trace and then proposes a noncircular gear-coupled five-bar linkage as a steering mechanism. It strictly follows the Ackermann steering rule compared with the existing four-bar steering linkages. Therefore, the method can be used to design any kind of planar five-bar linkage to satisfy a specified function of curves.

Chapter 5 introduces the theoretical foundation for the workspace of planar parallel mechanism under rotational actuations and the algorithms to search the reachable and the dexterous workspace. Then singularity workspaces of such mechanisms are presented with an application example of a planar 3-RRR linkage. The method and algorithm discussed in this chapter can be used to analyze other planar linkages.

Chapter 6 addresses the statics of some special planar linkages with the example of foldable stair proposed in Chap. 3. The statics of rigid-body system of the stair mechanism is first discussed. Because of the redundant constraints, the internal forces are examined by using the second Castigliano's theorem. And then the inner forces of every link are analyzed so that the engineers can execute an identical strength design.

Chapter 7 investigates the kinetostatics of overconstraint mechanisms which are made of double planar linkages. The mechanism is redundantly constrained in structure and therefore has both merits of high structural stiffness and strength of a truss structure and motion flexibility of a mechanism. The kinetostatics is discussed with the synthesis of a deployable wing frame and the lift mechanism.

Chapter 8 discusses a structural dynamics algorithm for foldable linkages based on transfer matrix. The foldable stair and deployable wing are all typical planar linkages which are made up of a number of identical units. Therefore, the dynamics of each link between every two adjacent revolute joints is precisely expressed by the transfer matrix of Euler-Bernoulli beam with the variables of boundary conditions of the joints. In this way, the structural dynamics of the whole structure can be developed by using the least variables compared with the traditional methods. In addition, this algorithm avoids the problem of the traditional transfer-matrix method that the number of variables greatly increases when there are a huge number of cross joints within a structure.

Chapter 9 proposes a foldable tower for supporting wind turbine whose height is changeable. The advantage of the flexibility to fold and unfold can be utilized for protecting the wind turbine when destructive weather comes. The dynamic equivalent stiffness of the foldable tower is investigated as the function of deployment angle of the actuator. To expand the applications of the foldable structures, multi-planar linkages and the topology changeable linkages are discussed at the end of this chapter.

Chapter 10 introduces the design of foldable mounting equipment for solar cell panels. The equipment consists of a number of identical brackets to fix the solar cell panels. Therefore, this chapter first investigates the geometry of each foldable unit and then focuses on statics of the structure and simulation experiments. When the bracket is deployed, the frame of each unit forms the space for fastening the solar cell panels through fixtures. The merit of the structure is that the whole structure occupies less space when completely folded. This is most convenient for transporting and manufacturing because of its less occupied space when folded. Meanwhile, it is also available to form arc-shaped or any spatial curved space panels by changing the positions of the middle joints of scissor units in assembly.

I am pleased to express my gratitude for the contribution of many teachers and colleagues whose work over the years has developed and clarified the design and analysis theory for overconstraint planar linkages. This book consists of results of the insight, commitment, and hard work by Jianyi Wang, Houlin Fang, Xiang Liu, Li Ye, Zhengfang Yan, Zheng Cai, and Huichan Zhao. I have also benefitted from the insight of my coauthors Zhijing Feng, Ning Ma, and Fulei Chu. In addition, I am grateful for the inspiration of Wenxiu Lu, Ketao Zhang, Guowu Wei, Ligang Yao, Daniel Martins, Jian S. Dai, Yuefa Fang, and J. Michael McCarthy.

Finally, I gratefully acknowledge the support of the Natural Science Foundation of China, the Natural Science Foundation of Beijing, the Foundation for the Author of National Excellent Doctoral Dissertation of China, and the Program for New Century Excellent Talents in University of Education Ministry of China and the support of State Key Laboratory of Tribology in Tsinghua University.

Tsinghua University, Beijing, China

Jingshan Zhao

Design of Special Planar Linkages

Zhao, J.-S.; Feng, Z.; Ma, N.; Chu, F.

2014, XII, 294 p. 330 illus.,

ISBN: 978-3-642-38448-6