Book Review

Mechanism design and configuration space

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The Configuration Space Method for Kinematic Design of Mechanisms
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Design of mechanisms for transferring motion and energy from an input link to an output link has been studied extensively since the Industrial Revolution – in the steam engine, invented by James Watt, widely acknowledged to have started the Industrial revolution, Watt designed a straight-line mechanism to pull and push the piston-rod. Traditional mechanisms are most often made with lower pair joints having area contact between the two connecting rigid bodies, and the design of such mechanisms is a mature and well-developed field. Nowadays, a large number of mechanisms, such as a cam-follower mechanism, are in use with higher pair joints where there are line or point contact(s) between two parts. This monograph is a creditable attempt to develop new tools and techniques for the design of mechanisms with higher-pair joints and mechanisms which have intermittent contact between parts. The key concept is that of the configuration space of a pair of contacting rigid bodies undergoing relative motion – a concept which has been also used by researchers for robot motion planning and assembly.

The monograph consists of 9 chapters and two appendices. Chapter 1 presents an introduction to mechanisms, its design, and provides an overview of the monograph. Chapter 2 deals with the representation of geometry of the parts of a mechanism, discusses the concept of the configuration space of a rigid body and the different types of joints (lower and higher pair) which can connect two rigid bodies. It also presents a classification of mechanisms and then goes on to show that there exist a large number of mechanisms with higher pairs and with intermittent motion. Chapter 3 deals with the contact of features, develops contact equations for different cases of contact of features, and provides numerical and analytical solution of the contact equations. Chapter 4 deals with contact of parts in the configuration space and presents algorithms to obtain partitions of configuration space. Chapter 5 deals with the kinematic analysis and simulation of mechanisms with configuration space partitions. Chapter 6 deals with the topic of tolerances and its effect on the kinematics of the mechanisms with higher pair joints. Chapter 7 focuses on the topic of kinematic synthesis and chapter 8 presents four case studies. Chapter 9 presents the main conclusions and directions for further research. The target audience of this monograph would be graduate research students and engineers in industry, especially those dealing with analysis and design of mechanisms with higher

pair joints and with intermittent motion. One of the main features of the book is the two appendices – in particular Appendix A which catalogues 30 mechanisms often used in industry. The book is easy to read and the figures are clear.

In contrast to mechanisms with lower pair joints, the geometry of the contacting surfaces plays a much more important part in the transmission of motion between the input and output in mechanisms with higher pair joints. Hence an important first step in design is to efficiently represent and manipulate geometry. A boundary representation and a feature-based approach are used to represent geometry of the parts, and this is illustrated with examples of a lever and a Geneva pair. The contact between two moving parts is dependent on the features and the geometry to the two contacting parts. The contact configurations involving simple planar features such as line and circular segments are derived and solved. For general segments, numerical strategies are suggested. The configuration space of a rigid body is the set of allowable positions and orientations, and can be represented by three or six variables for the planar and spatial case, respectively. When two rigid bodies are in contact and there is a relative degree of freedom between them, the configuration space can be partitioned into a) a free configuration, b) a blocked configuration, and c) a contact configuration partition. A key part of this monograph is to find these partitions, and chapters 3 and 4, the heart of this monograph, present the numerical and analytical techniques to obtain these. Several common cases, such as fixed-axis pairs, ratchet-pairs, Geneva pair, and general planar pairs are discussed in detail, and the configuration space partitions are obtained. Although chapters 3 and 4 are well written, most of the examples and the developed mathematics and algorithms are readily applicable only for planar mechanisms with one degree of freedom. It is known, and also mentioned by the authors in chapter 9, that it is difficult to obtain partitions of the configuration space for general spatial motions and/or multi-degree-of-freedom motions. Nevertheless, it would have been nice if the authors, who are well known researchers in this field, had presented their thoughts and ideas in more detail than in a couple of sentences in chapter 9 under ``research directions''. Mechanisms are also known to enter singular configurations where they gain a degree-of-freedom instantaneously or sometimes over a finite period. A discussion on singularities and the configuration space would also have been interesting. The kinematic simulation aspects in chapter 5 are dealt with clearly. The discussion on dynamic simulation, however, is too brief and is sketchy.

Chapters 6 and 7 deal with the important aspect of tolerances, inevitably present in all manufactured products, and their effect on the kinematic function of mechanisms with higher pair joints. One can easily visualize the importance of tolerances – in lower pair joints due to tolerances, a surface contact may reduce to a line or point contact, but in higher pair mechanisms, there may not be any contact and the kinematic function may not be achieved! Chapter 7 presents a useful parameter optimization algorithm to adjust parameter values such that a desired kinematic function is always achieved and the design is less sensitive to variations in parts.

The strongest part of the book is development of new CAD tools for design of mechanisms with higher pair joints. The weakest part is its limited scope and

applicability to primarily planar mechanisms. Planar mechanisms are no doubt important and possibly represent a significant majority of mechanisms used in industry. Nevertheless, mechanisms, robotics and CAD researchers would have loved to see new ideas and thoughts on possible extensions of the configuration space paradigm to spatial and multi-degree-of-freedom motions.

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