INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
8 & 9 SEPTEMBER 2016, AALBORG UNIVERSITY, DENMARK

A BRIEF INTRODUCTION ON THE KINEMATIC SCHEME DESIGN TEACHING SOFTWARE FOR MECHANICAL SYSTEMS

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ABSTRACT
Kinematic scheme design is the beginning of the mechatronic system design, which is the most important and difficult for junior students in mechanical engineering education. In this paper, the state space method with the idea of basic mechanism unit is introduced in kinematic scheme design of Theory of Machines and Mechanisms Course, which is expressed by state vectors, characteristics matrix and equations. Based on the basic mechanism unit, a database of the mechanism unit is set up, and computer aided teaching software of kinematic scheme design is developed for the teaching of Dalian University of Technology in China. By means of the software, the whole solutions of a mechanical system with a required input/output motion are generated though the combination of the basic mechanism unit. An example shows that the software is very helpful for the kinematic scheme design teaching and kinematic scheme design project practicing. It makes the kinematic scheme design teaching easy.

Keywords: Kinematic design teaching, basic mechanism unit, computer aided software.

1 INTRODUCTION

Kinematic scheme design, often regarded as a process that transforms a customer need or a desired function into a solution concept, is an important content of Theory of Machines and Mechanisms Course. Combining with the practice of project design in the course, to promote students' ability of kinematic scheme design of mechanical systems is one of the major goals in the course. Various colleges in domestic China have attached increasing importance to foster students' innovative design ability in Theory of Machines and Mechanisms Course. And the conceptual design of mechanical kinematic schemes allows students to cultivate their innovative thinking and improve their ability of analyzing and solving problems with their learning theories and knowledge.

However, due to the comprehensiveness of the design knowledge and the multiplicity of design solutions, it is always a challenge for instructors to help junior students, who just transit from basic theory courses to basic specialized courses and lack engineering experience, to master conceptual design skills. So how to tackle the challenge and promote teaching quality is a topic worthy of constant exploration [1-3].

To solve the conceptual design problems in Theory of Machines and Mechanisms Course teaching, this paper summarizes composition principles of mechanical systems and corresponding knowledge points and puts forward basic mechanism units. In addition, a computer aided software using the idea of the state space method [4-6] is developed to allow students to complete systematic conceptual designs with their learning knowledge. The software generates schemes of mechanical systems by mechanism units and their combinations in the database, which is surely beneficial to the teaching of Theory of Machines and Mechanisms Course.

2 MECHANISM UNITS AND THEIR COMBINATION

A mechanical system is usually made up of several mechanism units in series or parallel way. And the system's whole function is often described with a desired motion transformation from the input to the output mechanism unit. For example, a mechanical press, as is shown in figure 1, consists of a motor, a belt pulley, a gear train, and a slider-crank mechanism.

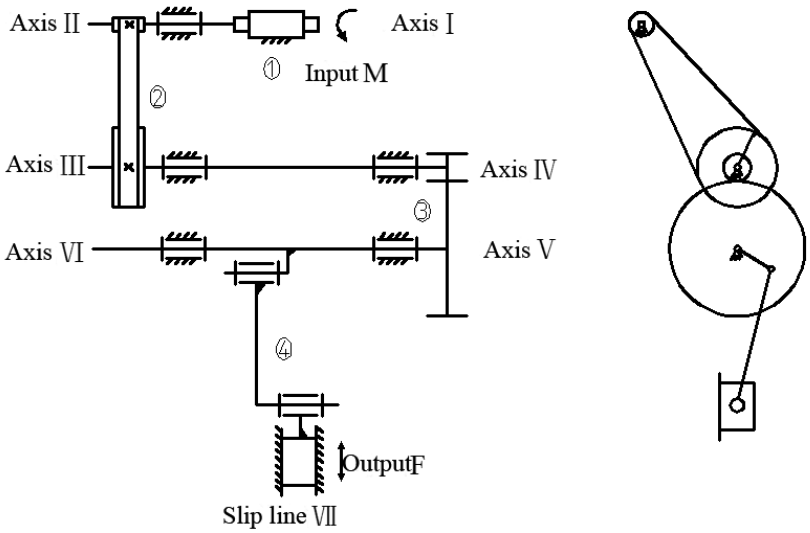


Figure 1. The schematic diagram of a mechanical press

A mechanical press needs transformation from the "continuous rotation motion" form into another "reciprocal translation motion" form, through the motion transmission and transformation along the mechanical press' composition chain, as is shown in Table 1.

Table 1. the motion transmission and transformation

No	Code	Name	Input motion	Output motion
①	W1	motor	electric energy	continuous rotation; Axis Ⅰ; torque M
②	W2	belt pulley	continuous rotation; Axis Ⅱ; torque M	continuous rotation; Axis Ⅲ; torque M
③	W3	gear train	continuous rotation; Axis Ⅳ; torque M	continuous rotation; Axis Ⅴ; torque M
④	V	slider-crank	continuous rotation; Axis Ⅵ; torque M	reciprocal translation motion; line VIII; force F

According to Table 1, each mechanism unit in the mechanical press implements a motion transformation, which can be described by input/output motion form pairs. An input or output motion can be expressed by state vectors, and the motion transformation from input to output can be expressed by characteristics matrix and equations. So, we can classify the mechanism units according to the types of input/output motion form pairs. For example, Table 2 describes the continuous rotation motion form input can be transformed to other motion form outputs.

Table 2. Motion transformation forms

Input motion	Output motion
continuous rotation	reciprocal translation
continuous rotation	intermittent reciprocal translation
continuous rotation	reciprocating oscillation
continuous rotation	intermittent reciprocating oscillation
continuous rotation	continuous rotation
continuous rotation	intermittent rotation
continuous rotation	desired trajectory

Since one input/output motion form pair can be achieved by various mechanism units, we can clarify the mechanism selection for kinematic scheme design by setting up a database of the mechanism units, as is shown in figure 2.

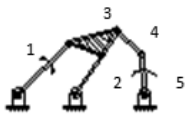
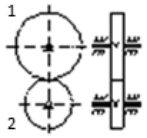
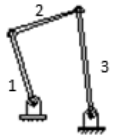
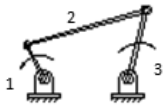
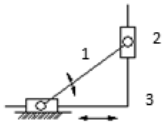
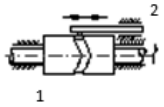
input motion	output motion	State transition matrix	Mechanism number	Mechanism name	2-D Legend
rotation	rotation	$T_{RR} := \begin{bmatrix} a_{1,1} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	CSixBDweRR	six-bar mechanism	
			CGearSpurG	External meshing spur gears	
			CFourBDbRo	double rocker mechanism	
			CFourBCrRo	crank and rocker mechanism	
rotation	translation	$T_{RT} := \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ a_{5,1} & 0 & 0 & 0 & 0 & 0 \\ a_{6,1} & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$	CFourbSin	sine mechanism	
			CFourSliCrTR	slider-crank mechanism	
			CSixBDweRT	Six bar mechanism with a moving pair	
			CCamCylCTrl	Cylindrical cam mechanism with straight moving push rod	

Figure 2. Database of mechanism units

Therefore, general mechanical systems can be generated by mechanism units in series, parallel or mixed ways based on the above basic mechanism unit library. The inverse algorithm of the combination operation and the specific technical route in kinematic scheme design of mechanical systems, were studied in the Ref. [5]. In simple terms, the kinematic scheme design process can be described as follows:

1. Abstract the input/output motion form pair of the entire machine.
2. Select elements from the Motion transformation database, similar to Table 2, and then combine them to achieve motion transformation.
3. Select specific mechanism units for each chain in motion transformation chains created in step 2.
4. Evaluation of results.

3 SOFTWARE IMPLEMENTATION WITH EXAMPLES

For ease of teaching, a kinematic scheme design software system was developed based on the above method, which applies the following technologies: Microsoft visual studio.net, Microsoft SQL Server, eXpressApp Framework, Matlab, Autodesk Inventor and so on.

In order to support complete design process, the system software provides basic kinematic transformation unit module, the design demand parameter configuration module, kinematic scheme solving module, mechanism combination algorithm module and project management module and so on.

For example, the design specifications of a mechanical press can be shown in Figure 3.

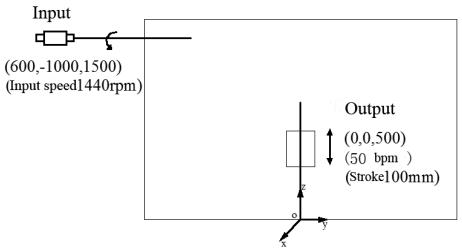


Figure 3. Design requirements of the press machine

The specification data should be inputted in the software, as shown in Fig. 4.

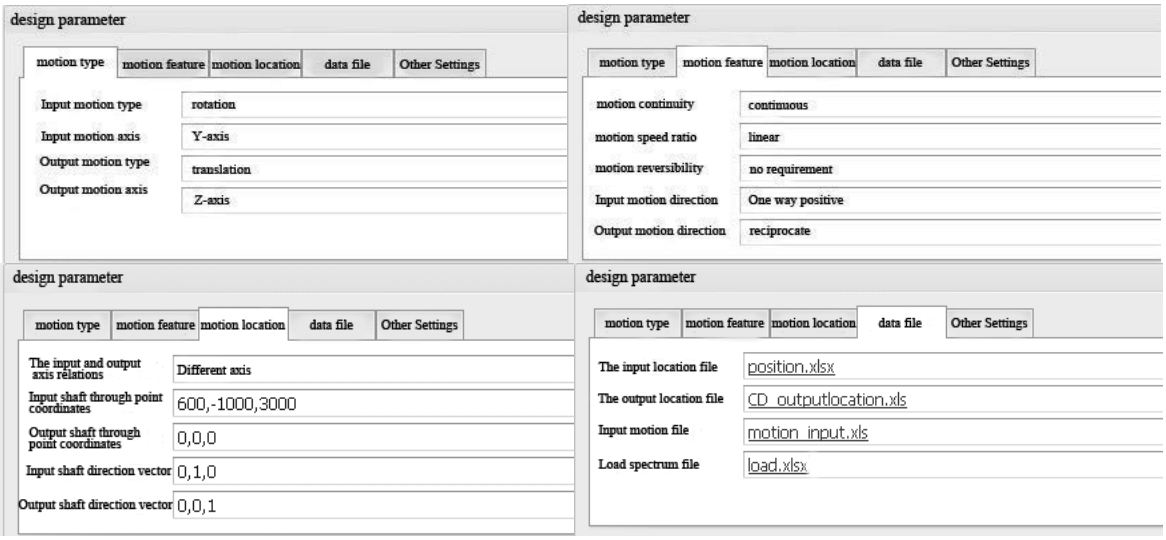


Figure 4. Data input

Then the system automatically solves the problem and gives some solutions, such as the results in Table 3.

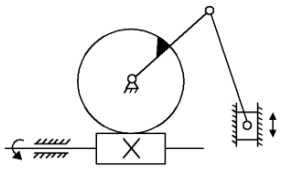
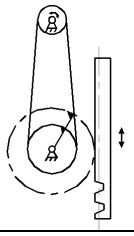
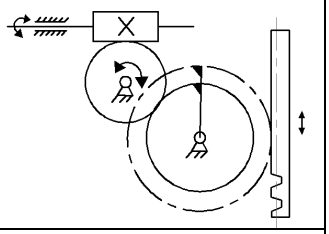
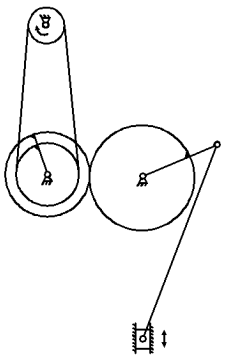
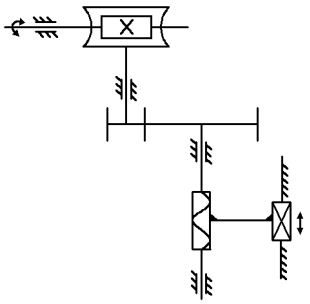
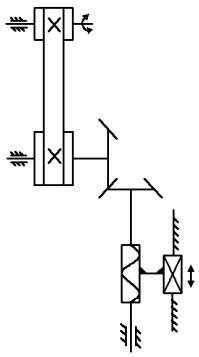
Table 3. Number of feasible solutions

Mechanism series	Number of schemes
Single stage	0
Double stage	52
Triple stage	566

Finally, some feasible combination schemes are shown in Table 4.

Table 4. Combination schemes of generated by software

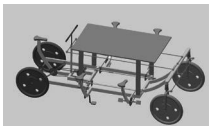
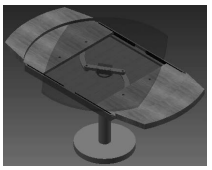
Number	1	2	3
Feasible scheme	Worm and gear + slider-crank mechanism	Belt drive +pinion and rack	Worm and gear + spur gear transmission with external meshing + pinion and rack

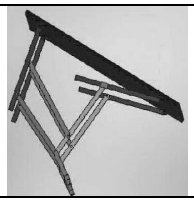
Schematic of mechanisms			
Number	4	5	6
Feasible scheme	Belt drive + spur gear transmission with external meshing + slider-crank mechanism	Worm and gear + spur gear transmission with external meshing + screw transmission	Belt drive + bevel gear + screw transmission
Schematic of mechanisms			

4 SOFTWARE APPLICATION

The kinematic scheme design software system has been applied in the Theory of Machineries and Mechanisms course teaching. A total of 78 students have participated in the project design of the Theory of Machineries and Mechanisms course and selected design themes by groups. With this software and related methods, students can get all feasible design schemes and select the best design scheme through the given input/output conditions. The software system has improved the design efficiency enormously, and has received highly applause from the students. The corresponding curriculum design examples are shown in Table 5.

Table 5. The students' curriculum design examples

Part of the group curriculum design topics	Input motion (vector expression)	Output motion (vector expression)	Examples of transmission schemes	3D model pictures
Sightseeing co-bike (112 solutions)	Continuous rotation $(0,\omega_2,0,0,0,0)^T$	Continuous rotation $(\omega_1,0,0,0,0,0)^T$	Chain drive+ bevel gear sets + chain drive	
	Reciprocal oscillation $(0,0,\pm\omega_3,0,0,0)^T$	Reciprocal Oscillation $(0,0,\pm\omega_3',0,0,0)^T$	four-bar linkage	
	Reciprocal oscillation $(\pm\omega_1,0,0,0,0,0)^T$ $(\pm\omega_1',0,0,0,0,0)^T$	Reciprocal Oscillation $(\pm\omega_1'',0,0,0,0,0)^T$	five-bar linkage	
Variable-sized table (92 solutions)	Continuous rotation $(0,0,\omega_3,0,0,0)^T$	Reciprocal rectilinear motion $(0,0,0,\pm v_1,0,0)^T$	Gear sets + four-bar linkage + screw mechanism + cylindrical cam	

Folding stage (489 solutions)	Reciprocal oscillation $(0,0,\pm\omega_3,0,0,0)^T$	Reciprocal oscillation $(0,0,\pm\omega_3,0,0,0)^T$	Six-bar linkage mechanism	

5 CONCLUSION

Kinematic scheme design teaching should be paid more attention, since it is not only helpful for the follow-up course study, but also critical for constructing the knowledge system in Theory of Machines and Mechanisms Course.

In this paper, a kinematic scheme design method is introduced and computer aided teaching software is developed for the teaching of Dalian University of Technology in China. Using the software, students can create more new design solutions easily and master the design method quickly. The practice has proved that it can make the kinematic scheme design teaching easy.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support of Dalian University of Technology Education Foundation and Innovation Education Foundation of Liaoning Provence of China.

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