Tentative Discussion on Teaching Practices of Basic Specialized Technical Course against the Backdrop of New Engineering Driven by Scientific Research

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Abstract. The Mechanisms and Machine Theory, a basic specialized technical course required for undergraduate students of mechanical majors at the authors' university, occupies an important position in the teaching plan for talent cultivation in higher education. To achieve a modernized teaching system, it is imperative to ensure students' acquisition of a solid foundation and interdisciplinary knowledge while emphasizing the development of specialized knowledge. Against the backdrop of new engineering, the relationship between science education and scientific research should be properly addressed in order to build a teaching- and research-oriented university. Students' initiative and innovative ability can be fully inspired and cultivated by progressively infiltrating the theoretical teaching with the instructor's research content, reasonably expanding the depth of knowledge in course design and properly applying relevant knowledge in experiments across all stages of course teaching.

Keywords: new engineering; basic specialized technical course; educational and teaching practices; adaptability; innovative ability.

1. Introduction

The Mechanisms and Machine Theory is not just a basic specialized technical course required for undergraduate students of mechanical majors enrolled in engineering universities, but also a "backbone" course for cultivating excellent mechanical engineers [1]. The course is more intimately related to practice than basic courses and more applicable and researchable than specialized courses. It serves as a connecting link between the proceeding and ensuing teaching plans in the undergraduate phase, and provides essential and basic specialized technical knowledge for designing and analyzing mechanical products. Therefore, it occupies an important position in the teaching plan for talent cultivation at the authors' university.

Since its establishment in 1951, the authors' university has been offering the course of Mechanisms and Machine Theory to students enrolled in mechanical and quasi-mechanical majors. Presently, full-time undergraduate students enrolled in majors of Mechanical Manufacturing and Automation, Mechanical-electronic Engineering, Robotics Engineering, Process Control and Automation have access to this course. The primary textbook for the course is Mechanisms and Machine Theory published by the Higher Education Press, with Sun Huan, et al., being its chief editor.

The course of Mechanisms and Machine Theory is comprised of three parts: theoretical teaching, experimental teaching and course design. Specifically, the teaching content and objectives of the course are outlined as follows: through learning of the course in combination with their prior knowledge learnt in courses like Advanced Mathematics, Mechanical Drawing and Theoretical Mechanics, students will be able to master the basic theories, calculation methods and design skills pertaining to conventional mechanisms (e.g., steering, landing gear and thrust-reverser mechanisms of airline planes, composition principles, structural analysis, design calculation and dynamic analysis of lathe, punching and slotting machine mechanisms). Apply this body of knowledge in special-purpose and general-purpose machines with motion and dynamic functions, have the preliminary ability to formulate plans for mechanism design, develop their ability in mechanism design and analysis, and foster innovative awareness. In the meantime, the course also aims to develop students' abilities to properly use, maintain and innovate mechanical products.

With respect to mechanism design and analysis methods, we have mainly adopted the graphic method, supplemented by the analytical method after fully taking into account the teaching content of the preceding courses offered in the university. The syllabus is developed based on the textbook and how well the students were prepared for learning. The previously blackboard-dominated teaching tools have shifted mainly towards multimedia presentation, complemented by blackboard writing. About one week is dedicated to course design, in which the graphic method is utilized to analyze the motion and force of 12 work stations over one motion cycle of the mechanism for general-purpose machines like the main cutting mechanism of a shaping machine, while the integrated mechanism design, as well as the motion and dynamic analysis of the retraction and extension processes, is employed for special-purpose machines like the front and rear landing gears of the B737 aircraft. The experimental teaching consists of 12 class hours, with a shift of teaching content from the monotonous demonstrative experiments towards hands-on experiments featuring integration and innovation.

With continuous reform and improvement in teaching processes, content and methodology, students' knowledge systems have been gradually deepened and strengthened. Questions as to "how to satisfy the needs of relevant industries and enterprises", "how to apply theories to resolve practical problems" and "how to begin" naturally follow. Against the backdrop of new engineering, how to resolve these questions with more scientific and effective methods and approaches has become one of the key issues to be addressed in the current education and teaching reform implemented in the university.

Many universities [2,3,4,5] have conducted in-depth research and reforms over the teaching objectives, content, methodology and forms of the course Mechanisms and Machine Theory. A consensus has been reached: instructors should start with the position of the course Mechanisms and Machine Theory in the system of mechanical courses, and uphold a philosophy that highlights the central position of design and analysis serving the design to eventually develop solutions to mechanical systems. Identify teaching objectives, develop teaching content and reflect teaching characteristics to cultivate students' comprehensive abilities in designing, innovating and addressing actual engineering problems by drawing on the latest achievements in technological advancement.

Education and scientific research are the two pillars for the construction of modernized universities. Universities are expected to cultivate a generation of future-oriented talents. In this regard, the core question is the modernization of the teaching system [6,7,8]. At the authors' university, a goal to build a "double first-class", teaching- and research-oriented university with regional characteristics has been proposed. Drawing upon the successful experiences from our counterparts in teaching the course Mechanisms and Machine Theory, under the premise of ensuring the observation of the syllabus and teaching quality, and combining instructors' research project with various teaching processes, we have carried out some preliminary explorations and attempts to cultivate students' awareness of interdisciplinary engineering and improve their design, analytical, practical and innovative abilities.

2. Deepening the Theoretical Teaching

The conventional knowledge and teaching content contained in the course Mechanisms and Machine Theory are undeniably compulsory. At the authors' university, the theoretical teaching of the course focuses on the design and analysis of the Ⅱ-degree mechanisms within limited class hours. Presently, the graphic method is mainly utilized for mechanism design and analysis, as the method not only entails simple, intuitive design analysis and explicit meanings, but it also helps address the initial value calculations required by the analytical method. Nevertheless, graphic analysis is, after all, a method employed on single mechanism regions, which is unable to reflect the dynamics of a mechanism in cyclical continuous motion and involves poor calculation accuracy when applied on modern machines.

To satisfy the actual engineering needs, instructors should follow the "new engineering" concept and try to make the course more relevant to modern mechanical research and development. By progressively infiltrating the processes of theoretical teaching with the knowledge, concept and methodology related to the instructor's research projects, instructors will be able to not only fully

present the most fundamental and central knowledge contained in the course of Mechanisms and Machine Theory, but also reflect the latest developments, trends and methodologies of the discipline that the course falls into.

In theoretical teaching, the instructor should take into account students' cognitive ability and knowledge structure, and incorporate the elements of knowledge derived from the instructor's research into teaching in a timely and appropriate manner, while ensuring the teaching content is purposeful, organized and methodological. For instance, for Mechanism Design, Motion and Dynamic Analysis is a key and difficult part in theoretical teaching, we divided the theoretical teaching into four steps based on the sequence and degree of difficulty of this knowledge body:

Firstly, after the instructor has explained the calculation of kinematic pair and the degree of freedom of mechanisms, the composition of mechanisms and structural analysis, students are directed to review and summarize the principles of relative motion and balance of force in Theoretical Mechanics and the graphic method of vector equation in Advanced Mathematics. Next, an explanation to the graphic method of vector equation associated with mechanism motion and force is provided. Finally, the advantages and drawbacks of the graphic method are analyzed, thereby introducing the analytical method.

Secondly, the question of how to use mathematical tools like the complex number method, matrix method and polar coordinate method to solve the closed loop vector equation of motion analysis is explained. Despite the high accuracy of solutions derived from the analytical method, the calculation process is rather complex for complicated mechanisms as the material attributes, mass parameters and frictions should be taken into account. It follows that whether there is a method that can not only effectively address the motion and dynamic problems of complicated mechanisms under the premise of fully considering the actual working conditions, but also test the correctness of mechanism design before the product is finished. The 3rd and 4th teaching steps are thus educed.

Third, the instructor may allocate a short period of time in class to purposefully interweave and demonstrate the achievements and methodologies applied in his or her research projects, such as the design, analysis, application and domestic and foreign research frontier related to spatial mechanisms of robotics and manipulators.

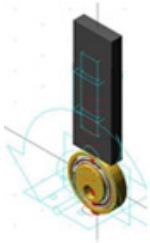
Fourth, introduce the computer-aided design and analytical tools commonly used by instructors in their research, such as the commercial mathematical software MATLAB designed by the U.S. MathWorks company, the C-programming design software. The 3D mechanical CAD software Pro/ENGINEER developed by PTC and the virtual prototype software ADAMS developed by MSC. In the event that the thermal, deformation and strength problems of a mechanism are considered, the finite element computation software ANSYS, which is prominent for solving Multiphysics coupling problems, can also be used. These four groups of software can collaboratively address the design, calculation, 3D modeling, and motion and dynamic analysis of mechanisms. Using these software suites, we can transform the resultant 2D, static figures related to mechanism design and analysis in traditional theoretical design into 3D, dynamic and digitalized models. The composition and motional process of mechanisms are presented in a lively and lifelike way; the calculation of motion and dynamics becomes simple and accessible; and the calculation results of stress and deformation displayed in the form of color maps are comprehensible at a glance.

In class, the instructor purposefully combines teaching with scientific research across the explanative and demonstrative processes. Such a teaching approach not only helps strengthen students' integrated cognition to fragmented elements of basic knowledge, make the complicated and monotonous theories comprehensible and acquirable, and ensure the continuity and effectiveness of the teaching content, it also inspires students' interest in solving actual engineering problems, and extends the scope of the teaching content.

After class, some students would voluntarily request to join the research project led by the instructors. We carefully selected an array of actual engineering problems highly relevant to our theoretical teaching, and employed a method combining coaching with self-learning and computer-aided design with analysis allowing students to independently complete calculation and analysis for

their designs. These measures have further fostered and improved students' confidence and ability to solve actual engineering problems.

Fig 1- Fig 2 presents the calculation results of dynamic displacement of an eccentric disk cam gearing and a cam carrier in an automatic material transportation device independently designed by students.



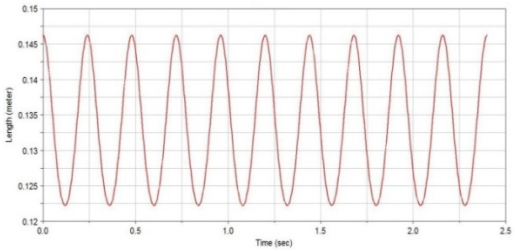


Fig.1 The dynamics model of an eccentric disk cam gearing Fig.2 The displacement of follower

Based on the calculation results of the design, the geometric models of the eccentric disk cam gearing mechanism of the automatic material transportation device were constructed using the Pro/E software. Then the kinematic pair, excitement, friction and material attributes were incorporated into the ADAMS software to carry out mechanism dynamics simulation calculation. The results show that:

The motion of the follower is smooth. The displacement, stroke and motion of the cam meet the design requirements.

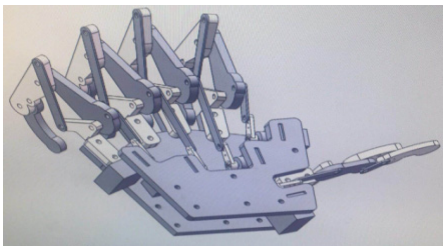
3. Extending Course Design

As articulated in the National Science and Technology Innovation Conference in 2012, the fundamental reason that China fails to become a manufacturing power is the poor innovative capability of enterprises, appropriately dealing with the relationship between scientific research and popularization of science education remains a top priority.

The course design module of Mechanisms and Machine Theory falls into the practical teaching part of the course. This module aims to further strengthen and deepen the theoretical knowledge acquired by students, allow them to independently solve the real-world problems related to the course and further improve their abilities to design, analyze and consult relevant technical data. Orchestrating the research achievements obtained by the instructors or content related to on-going research project into course design and teaching, and properly introducing and reasonably deepening the topic of course design can improve students' perception and design ability pertaining to the composition principles of machines and mechanisms, as well as design and analysis related to them. In the meantime, these measures also help students lay a solid foundation for learning ensuing specialized courses.

Based on the preparedness of undergraduate students at the authors' university, the topics of course design were assigned on a voluntarily selected basis. Guidance with correlation theories, design calculation, analytical methods, program application, and software support was provided based on the instructor's research project. After the tasks were specified, students were divided into teams and groups where they worked in collaboration from scheme planning, structural design, comprehensive analysis to finished product. This will give full play to their initiatives in the preliminary design.

Fig 3-Fig 7 are respectively the 3D models of the grasping manipulator and the single cylinder four-stroke internal combustion engine completed by undergraduates of author's university, as well as the piston motion and connecting rod stress calculation results.



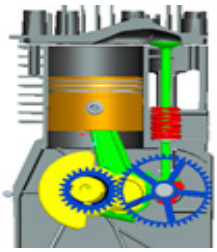
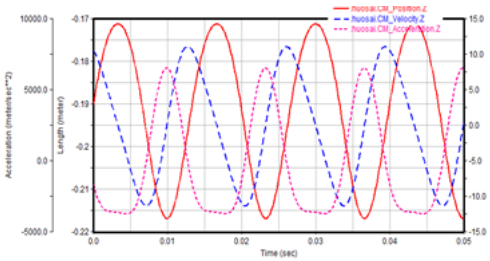


Fig.3 The grasping manipulator Fig.4 The single cylinder four-stroke internal combustion engine



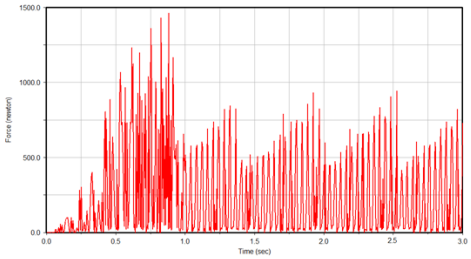


Fig.5 The displacement, velocity, and acceleration of the piston Fig.6 The force on the piston

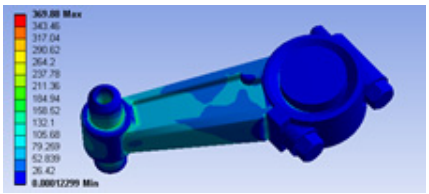


Fig.7 Stress distribution of connecting rod

Driven by 5 motors, the grasping manipulator features well-collaborated finger joints which formed by planar linkage mechanisms and can flexibly perform grasping and releasing operations.

Based on the calculation results of the design, the geometric models of the single cylinder four-stroke internal combustion engine were constructed using the Pro/E software. Then the kinematic pair, excitement, friction and material attributes were incorporated into the ADAMS software to carry out mechanism dynamics simulation calculation. Using the load basis derived from the mechanism dynamic calculation, a finite element calculation model of the connecting rod was constructed using the ANSYS software. The results show that:

(1) The motion of the piston connecting rod mechanisms is smooth, and the displacement, stroke and motion of the piston meet the design requirements.

(2) The maximum stress of the connecting rod falls within the allowable range of the material and meet the design requirements.

4. Providing Additional Experimental Projects

The experimental teaching module of the Mechanisms and Machine Theory is more intimately related to practice and comprehensibility compared with theoretical teaching. It plays an irreplaceable role in cultivating innovative talents with integrated qualities of knowledge, competency and skills.

At the authors' university, there are 6 laboratories subordinated to the lab center of mechanical design, where the experimental teaching related to courses of Mechanisms and Machine Theory, Mechanical Design and Fundamentals of Mechanical Design is conducted. Under the new circumstances, the theoretical teaching has been blended into laboratory construction and experimental teaching so they could mutually reinforce each other. The teaching- and research-oriented experiment projects are also being piloted and explored.

To give priority to developing students' potentials, their knowledge structures should be fully taken into account and the content of scientific research should be proportionally incorporated into

experiments to provide students with training that place equal importance to teaching and learning, as well as theory and practice. In the meantime, students should be encouraged to voluntarily engage in, explore and innovate the experiments so as to improve their engineering literacy, innovative ability and comprehensive practical and applicable abilities.

To that end, the teaching and research team adopted an approach similar to that applied in course design based on the innovative experiment projects established by the university for students. That is, a method integrating teaching and self-learning was applied after repeated practices and distillation to provide part of additional experimental projects for students with approved research projects. Students were required to analyze and solve problems independently, perform 3D modeling and complete finished products through 3D printing or machine processing. These measures realized a whole range of processes from self-made mechanisms, product assembly, calibrate to stereotyping.

Fig 8-Fig 11 present the obstacle crossing robot, the model of the main part of a turboprop gas turbine rotor, the rotary and clamping mechanisms of a transportation device independently modified and designed by students' research experiment teams.

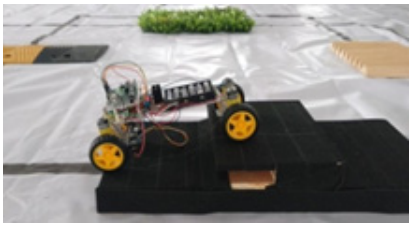


Fig.8 The obstacle crossing robot

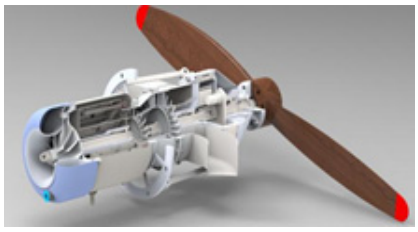


Fig.9 The turboprop gas turbine mechanism

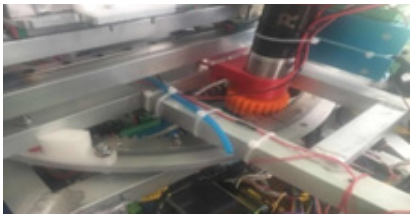


Fig.10 The rotary mechanism

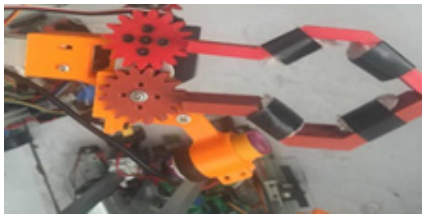


Fig.11 The swing clamping mechanism

During the experiment, some students have fully leveraged their expertise in programming, modeling and software application to debug programs, construct models and perform analyses. Other students utilized their hands-on capabilities to process, assembly and calibrate mechanisms. All these activities have improved their collaborative, practical and innovative abilities. Students have gained a sense of accomplishment after seeing their theoretical knowledge verified and improved, and in the same time, they also perceived many drawbacks which may prompt them to more actively and purposefully overcome them in future learning.

5. Development Plan for Course Teaching

Across all teaching processes of the course of Mechanisms and Machine Theory, the content of scientific research has been progressively infiltrated into theoretical teaching, depth has been appropriately achieved in course design and experimental projects have been properly applied. All these measures have successfully combined concepts, thoughts and design with real-world applications to inspire and activate students' initiative.

Presently, the course of Mechanisms and Machine Theory is offered to students enrolled in four different majors at the authors' university during the 1st or 2nd semester of the third academic year. Greater outcomes can be achieved if we could provide other courses related to electromechanical control, sensors, signal detection and processing as preceding or simultaneous course, combine the content derived from textbooks and instructors' research projects into the target course, take into account students' knowledge structure and practical needs. Re-formulate teaching standards against

the backdrop of new engineering. Screen, supplement, update and recombine the theoretical and practical teaching in a more scientific manner, draw on the "mixed" teaching approach and further integrate teaching content and methodologies. The teaching effect of this course will be better than before.

For instructors, the relationship between teaching and research should be properly addressed while giving priority to cultivating students' various abilities. While striving to promote teaching with research, instructors should also promptly discover problems arising from teaching and examine them, so as to facilitate the interaction, mutual transformation and improvement between teaching and scientific research.

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