Application of ADAMS Virtual Simulation Technology in Theoretical Mechanics Teaching Under the Background of New Engineering Disciplines

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Abstract: Initiated to address the demands of technological revolution and industrial transformation, the Emerging Engineering Education (3E) Plan aims to cultivate interdisciplinary talents with enhanced practical and innovative capabilities, while traditional theoretical mechanics education faces challenges like theory-practice disconnection and outdated curricula. This study employs ADAMS-based simulation methods to analyze complex static and kinematic problems, demonstrating that ADAMS achieves high-precision solutions (<3% error in statics, <0.1mm in kinematics) and significantly improves computational efficiency (50× faster than analytical methods) while maintaining strong experimental validation consistency (>95%). The results confirm that ADAMS effectively bridges the gap between theoretical instruction and practical application, offering a powerful tool for modernizing engineering education and supporting the goals of the 3E Plan.

Keywords: ADAMS; Theoretical; Mechanics Statics; Kinematics; Demonstration of an Instance

1. Introduction

In response to the demands of the new round of scientific and technological revolution and industrial transformation, and to better serve major national strategic deployments and regional economic and social development, the "Emerging Engineering Education Plan" (3E Plan) has been formally proposed and implemented in recent years [1]. This initiative focuses on the development trends of future emerging industries, with particular emphasis on cultivating high-quality interdisciplinary engineering talents with solid practical engineering capabilities, outstanding innovative spirit, and remarkable international competitiveness. Compared with traditional engineering education systems, the 3E Plan demonstrates three distinctive characteristics: first, greater emphasis on the cutting-edge nature and applicability of disciplines; second, stronger focus on interdisciplinary integration; and third, more prominent comprehensiveness of knowledge systems. Its professional fields encompass next-generation information technologies such as artificial intelligence, big data analytics, and the Internet of Things, as well as strategic emerging industries including biotechnology and sustainable development, forming a future-oriented new engineering education system.

Amid the wave of emerging engineering education, higher education institutions must deeply understand its core principles and diligently advance its implementation. Guided by the mission of fostering virtue and nurturing talents, they should adopt a forward-looking approach to adapt to changes and shape the future. Through inheritance and innovation, interdisciplinary integration, and coordinated development, they must integrate knowledge impartation, skill cultivation, and value shaping into every engineering course.

As a core course in engineering education, theoretical mechanics aims to strengthen students' foundational theoretical knowledge and develop their ability to analyze and solve practical engineering problems. However, the teaching of theoretical mechanics faces several challenges [2,3]. First, traditional teaching methods emphasize the indoctrination of theoretical knowledge, focusing on abstract concepts and formulas while lacking connection to real-world engineering problems. This often prevents students from translating theoretical knowledge into practical solutions. Second, as engineering fields evolve rapidly with continuous technological advancements, the teaching resources for theoretical mechanics lag behind. Students, however, need exposure to the latest engineering applications and technological developments to meet future career demands. Additionally, the emerging engineering education initiative emphasizes interdisciplinary integration and comprehensive skill development. Traditional theoretical mechanics courses often concentrate solely on discipline-specific knowledge, lacking multidisciplinary expansion and integration, which hinders the cultivation of students' comprehensive innovative abilities and interdisciplinary thinking [4].

As a fundamental core course in engineering education, theoretical mechanics serves dual purposes: establishing students' theoretical foundations while developing their problem-solving capabilities for engineering applications. However, current pedagogical practices in this discipline exhibit notable limitations [2-5]. Specifically:

(1) Traditional teaching overemphasizes unidirectional knowledge transmission through abstract concepts and mathematical formulae, failing to bridge theory with practical applications, which hinders students' knowledge transfer abilities.

(2) Course content updates lag behind rapid technological advancements in industry, creating gaps in students' understanding of cutting-edge engineering applications.

(3) The interdisciplinary integration required by emerging engineering education conflicts with the single-disclosure isolation of conventional curricula, ultimately restricting the cultivation of students' comprehensive innovation competencies.

2. Analysis of the Current Teaching Status in Theoretical Mechanics Courses

2.1 Excessive Emphasis on Abstract Theory

In current pedagogical practices of theoretical mechanics courses, there persists a significant overemphasis on abstract theoretical concepts and formulaic derivations, often at the expense of contextualizing foundational knowledge within real-world engineering challenges. While theoretical frameworks and mathematical deductions are indispensable for establishing systematic disciplinary structures and fostering deep comprehension of physical phenomena—and indeed form the cornerstone of the curriculum—this excessively dry and theoretical approach frequently neglects practical connections to engineering applications. As a result, students often struggle to grasp the practical relevance and implementational significance of the theories they learn. Although such methods ensure a solid command of fundamental principles, they fail to equip students with the necessary skills to effectively translate theoretical knowledge into practical solutions for engineering problems [5].

2.2 Teacher-Centered “Cramming” Pedagogy

As a fundamental yet challenging engineering course, theoretical mechanics requires students to deepen their understanding and mastery of knowledge through solving practical problems. However, current teaching practices predominantly rely on instructor-led, one-way knowledge transmission, which significantly limits student participation and neglects the cultivation of hands-on abilities. Passive learning approaches—such as listening and note-taking—prove insufficient in developing the practical skills and problem-solving competencies needed to address real-world engineering challenges. This teacher-centered model further restricts students’ active engagement and inhibits their capacity for independent exploration.

2.3 Insufficient Teaching Resources

Teaching cases and practical examples play a vital role in theoretical mechanics courses by bridging abstract theoretical concepts with real-world engineering problems, thereby enhancing students’ comprehension and application of knowledge. However, due to limitations in teaching platforms and resources, current instructional practices often lack sufficient engineering-oriented case studies [6]. This shortage restricts students’ exposure to authentic engineering scenarios, impedes the development of their practical application abilities, and ultimately hinders their capacity to translate theoretical knowledge into real-world solutions.

2.4 Lack of Interdisciplinary Integration

Current teaching practices in theoretical mechanics suffer from insufficient integration with other disciplines. Firstly, the traditional curriculum tends to focus heavily on purely theoretical content, neglecting meaningful connections with related fields such as engineering design, materials science, and computer simulation. While students learn the concepts, principles, and formulas of theoretical mechanics, they receive limited exposure to complementary disciplines. This single-subject instructional model restricts their ability to understand and address comprehensive, real-world problems [7].

Secondly, the course often lacks connection to practical application scenarios. Real-world engineering challenges typically require the comprehensive application of multidisciplinary knowledge [8]. However, students seldom have opportunities to apply theoretical mechanics to authentic engineering contexts. As a result, they struggle to relate specialized knowledge to practical problem-solving, hindering the development of an integrated professional knowledge system and the ability to tackle complex interdisciplinary issues.

Updating teaching content serves as the foundation for curriculum reform. Integrating course material closely with real-world engineering practice can enhance students' professional skills and lay a solid foundation for subsequent specialized courses. Therefore, in theoretical mechanics courses, it is essential to promptly update teaching content and incorporate more engineering-oriented cases and materials.

Specifically, the statics section should emphasize force analysis and select examples commonly used in courses such as Mechanical Principles and Mechanical Design—such as cantilever beams and lifting devices—to develop students' modeling skills and practical problem-solving abilities. In the kinematics section, students should be encouraged to actively explore particle kinematics and basic rigid-body motions. Detailed case studies of mechanisms such as cam systems and slider-crank mechanisms can strengthen their understanding of composite particle motion and planar rigid-body motion. For the dynamics portion, the focus should be on explaining the application of dynamic methods in engineering practice, supported by relevant examples, to cultivate students' analytical and problem-solving capabilities.

Thus, the update of teaching content should be closely aligned with engineering practice, highlighting force analysis, composite motion of particles, planar motion of rigid bodies, and the practical application of dynamic methods. Such a teaching approach will improve student learning outcomes, better prepare them to address real engineering challenges, and establish a strong foundation for further specialized courses [9].

In addition, content updates should also emphasize innovation in teaching methodologies. Traditional teaching methods in theoretical mechanics often overemphasize one-way knowledge transmission from instructor to student, neglecting active participation and practical skill development. Therefore, interactive teaching, problem-based learning, and collaborative teamwork can be adopted to encourage students' active involvement in class discussions and hands-on activities, thereby fostering comprehensive competencies and interdisciplinary thinking.

In summary, to meet the talent development goals of emerging engineering education, it is imperative to reform the teaching of theoretical mechanics. Enhancing instructional quality will help expand the depth and breadth of students' expertise and cultivate their capacity for integrated innovation and practical problem-solving [10].

3. Adams' Advantageand Examples in Statics

ADAMS is a multi-body dynamics simulation flagship software developed by the American MSC Software Corporation. As the world's first commercialized multi-body dynamics platform, its core solver is based on the Roberson-Wittenburg multi-body system dynamics theory, and it has now become the standard analysis tool in the fields of autom, aerospace, military, etc [6]. The latest version of ADAMS 2023.1 integrates digital twin and AI optimization models. Its advantages in the aspect of statics are mainly as follows:

1.System Equilibrium Solution: Automatically calculates static equilibrium positions for complex mechanisms, supporting frictional contact systems (200+ contact pairs) with <3% error.

2.Constraint Force Analysis: Outputs 6-DOF force/moment matrices for joints and visualizes force transmission paths, achieving 5-8x faster computation than FEM.

3.Stability Evaluation: Determines system stability via Jacobian matrix eigenvalues and generates parameterized stability boundary curves.

4.Engineering Validation: Applied in crane load optimization and steel structure strength verification, showing >95% consistency with experimental data size and Helvetica style, capitalized similar to paper title, aligned center and bold face. Source (if any) appear underneath, flush left. Figures should be at good enough quality.

For Example: The support load and size of the plane arbitrary force system are shown in Figure 1. It is known that $F_1 = F_2 = 0$ kN, and the constraint forces at the hinges A, B, and C are to be determined. Using the ADMAS part modeling tool, a simulation model is, and the constraint tool is used to add constraints between components, and the loads $Q_1 = 10$ kN, $Q_2 = 10$ kN are added to the actual structure and load of the support, as shown in Figure 2.

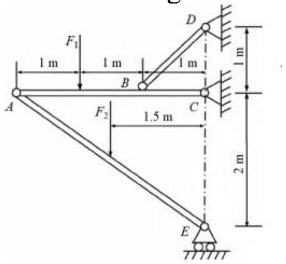

Figure 1. Arbitrary Force System Support Structure

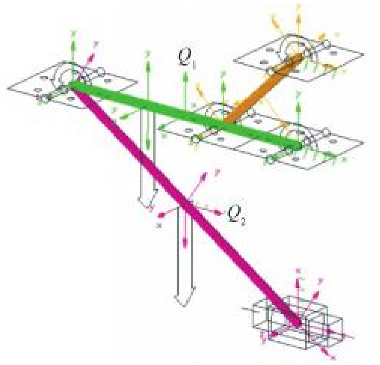

Figure 2. Arbitrary Force System Support Structure ADAMS Simulation Model

After the model is built, the simulation is run, and the constraint force at point A is 5kN, as shown in Figure 1; the constraint force at point B is 49.5kN, as shown in Figure 2; the constraint force at point C in the direction is -35kN, along the negative direction of the X axis of the constraint Marker point, i.e., the force of the AC rod on point in the X direction is to the left along the AC rod, according to the law of action and reaction, the constraint force of point C on the AC rod is to the right 35kN, the constraint force of point C in the Y direction is 20kN, along the negative direction of Y axis of the constraint Marker point, i.e., the force of the AC rod on point C in the Y direction is downward, according to the law of action reaction, the constraint force of point C on the AC rod is upward 20kN, and these simulation results are completely consistent with the theoretical analytical solution of the problem.

4. Adams' Advantageand Examples in Kinematics

1.Fully-Parameterized Motion Solving: Automatically computes position/velocity/acceleration tri-level kinematic quantities, supporting 20 DOF mechanisms with <0.1mm displacement accuracy

2.Singularity Handling: Embedded auto-detection and avoidance algorithms achieving >98% success rate in complex trajectory planning

3.High-Efficiency Solving: KINEMATICS solver delivers 50x faster computation than analytical methods

4.Engineering Validation: Successfully applied in robotic arm trajectory optimization and vehicle steering analysis with <0.5°/s angular velocity error

For Example:

The problem of constrained motion is a kinematic analysis of the displacement of a body in which a four-bar mechanism is considered as shown in Figure (1). $O_1A = O_2B = 10$ cm, $O_1O_2 = AB$, and the link O_1A rotates about the axis O_1 with angular velocity $\omega = 2$ rad/s. A cylinder C is attached to the bar AB and is connected to the rod CD by a hinge joint. All the parts of mechanism are in the same vertical plane. Find the velocity and acceleration of the rod CD when $\varphi = 60°$.

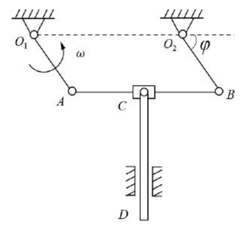

Figure 3. Hinge four-Bar Linkage Model

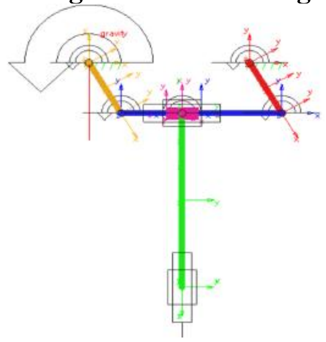

Figure 4. Hinge Four-Bar Mechanism Adams Simulation Model

Firstly, the three-dimensional structural simulation model was established with the ADMAS part modeling tool, and the constraint tool was used to add constraints the parts: REVOLUTE JOINT was used between O_1, O_2, point A, point B, the slider and the CD rod, and TRANSLATIONALJO was used between the slider and AB, between the CD rod and the track, and the MOTION_ROTATION motion was added to the hinge constraint on the O_1 axis simulate the actual constraints and motion of the mechanism, as shown in Figure 3. After the model was built, the simulation was run, and the POSTPRESSOR tool was used to obtain the curve of the velocity and acceleration of point C on the CD rod changing with the movement of the mechanism through the measuring tool, as shown in. Figure 4. On the curve, when φ=60o, the velocity of the CD rod is 10 cm/s, and the acceleration of the CD is 34.6 cm/s2, which is the same as the theoretical analytical solution result of the velocity synthesis and acceleration synthesis theorem of the through point.

5. Convected Motion Represents a Typical Case Study in the Kinematic Analysis of Rotation About a Fixed Axis.

The kinematic analysis of convected motion involving rotation about a fixed axis presents greater complexity compared to purely translational convected motion due to the additional Coriolis acceleration component. Both the identification and computation of Coriolis acceleration pose significant challenges for many beginners. Through ADAMS kinematic simulations, which leverage built-in dynamic solving algorithms, velocity and acceleration analyses can be performed automatically, enabling intuitive and precise solutions. Integrating ADAMS simulations into classroom teaching serves as an effective demonstration and practical example for explaining this topic, thereby deepening students' understanding and stimulating their learning interest.

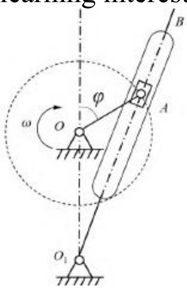

Figure 5. Schematic Diagram of Crank-Rocker Mechanism

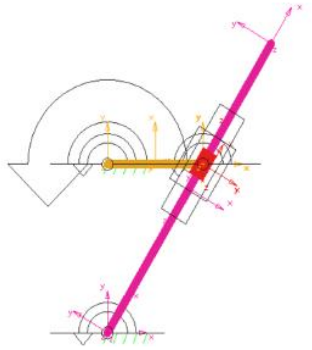

Figure 6. ADAMS Simulation Model of Crank-Rocker Mechanism

Taking the crank-rocker mechanism shown in Figure 5 as an example—where the crank length OA = 12 cm rotates uniformly at ω = 2 rad/s about point O, driving the rockerO_1B to swing aboutO_1 via slider A, withOO_1 = 20 cm—determine the angular velocity and angular acceleration of the rocker when φ = 0° and φ = 90°.

The three-dimensional simulation model was constructed using ADAMS part modeling tools. Constraints were applied between components with constraint tools: REVOLUTE JOINTS were applied at points O, O_1, and the connection between the slider and link OA; a TRANSLATIONAL JOINT was used between the slider and rocker O_1B. Additionally, a MOTION_ROTATION was added to the revolute constraint on the O_1 shaft to simulate the actual constraints and motion of the mechanism, as shown in Figure 6. After completing the model, the simulation was executed. Using the POSTPROCESSOR tool and measurement functions, the curves of angular velocity and angular acceleration of rockerO_1B versus the mechanism's motion were obtained.

The results show that when φ = 0°, the angular velocity of rockerO_1B is 2.63 rad/s with zero angular acceleration; when φ = 90°, the angular velocity is 1.86 rad/s and the angular acceleration is 10.2 rad/s². The simulation results are consistent with the theoretical analytical solutions derived from the velocity composition theorem and acceleration composition theorem.

6. Conclusion

Based on the mechanical analysis kernel of ADAMS, simulation analysis is carried out, and the simulation results are demonstrated in the form of animation, curve and otherized forms, so that the abstract mechanical concepts and knowledge become intuitive and vivid. By comparing and analyzing the theoretical analytical solution with the ADAMS simulation results, the interest of students in is stimulated, and the teaching quality is improved while the classroom teaching content is enriched, and the students' understanding of mechanical phenomena and knowledge points is deepened.

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