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Exploration of Teaching Innovation Based on Mechanical Engineering Control Theory Course

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Abstract: To better adapt to the intelligent development trends of modern manufacturing, how to conduct educational and teaching innovation has become a research hotspot in the field of mechanical engineering education. As a core compulsory course for undergraduate mechanical engineering programs, Modern Mechanical Control Engineering course significantly impacts the teaching quality and student development. However, the existing courses on mechanical engineering control theory face issues such as outdated teaching methods, incomplete assessment method, and students lacking practical engineering experience. There is an urgent need for teaching innovation exploration to better cultivate comprehensive talents with solid foundational knowledge and innovative practical abilities. This paper explores multi-dimensional teaching innovation for this course through multiple methods including diversified assessment methods, integrating ideological and political education in classroom teaching, combining theoretical knowledge with engineering projects, and MATLAB-aided simulation experiments teaching. These teaching innovation methods contribute to cultivating innovative engineering talents for the new era and provide a reference method for how other disciplines might approach teaching innovation.

1. Introduction

With the rapid development of modern manufacturing, the demand for innovative multidisciplinary engineering talents is growing increasingly strong. Mechanical Engineering Control Theory course is a core compulsory course for undergraduate mechanical engineering programs, it serves as a vital connecting link between prerequisite fundamental courses and subsequent specialized courses. Addressing the extensive demand for automation control technology in the fields of defense, industrial applications, civil life, this course primarily focuses on fundamental theories, working principles, and analytical methodologies related to classical control theory. It equips students to perform preliminary design, performance analysis, and system compensation for complex linear systems in mechanical control domains. This course cultivates students' ability to apply control theory knowledge in analyzing, investigating, and solving complex engineering problems, while establishing essential theoretical foundations for future professional technical work and scientific research[1]. However, the current course suffers from some problems in teaching and it's urgent to perform teaching innovation to better cultivate comprehensive talents with solid foundational knowledge and innovative practical abilities[2].

2. Course Content and Assessment Methods

2.1. Course Content

The Mechanical Engineering Control Theory course deeply integrates mechanical engineering knowledge with classical control theory knowledge. As a highly comprehensive course, it requires students to synthesize foundational knowledge from multiple prerequisite courses including Advanced Mathematics, Linear Algebra, Complex Variables, Electronic Circuits, College Physics, Hydraulic Transmission, and Mechanical Principles to analyze systems. This course lays a solid theoretical foundation for students to engage in mechanical design, automatic control, and system research, enabling them to better adapt to the intelligent development trends of modern manufacturing. The course content mainly consists of six parts: Introduction, Mathematical Modeling of Systems, Time-Domain Response Analysis, Frequency-Domain Characteristics Analysis, Stability Analysis, System Performance Indicators and Compensation. Each section encompasses extensive and broad-ranging knowledge.

2.2. Diversified Assessment Methods

The traditional assessment method for undergraduate courses mainly relies on final exams. Although it is simple to implement, it has many drawbacks. This assessment method neglects the learning process, causing students to focus more on memorization rather than applying professional knowledge in order to pass the exams[3]. As a result, it is difficult to meet the requirements for cultivating innovative engineering talents in the new era. Therefore, it is necessary to establish a multi-dimensional comprehensive assessment method for the Mechanical Engineering Control Theory course instead of the traditional final exam assessment method to cultivate comprehensive talents with solid basic knowledge and innovative practical abilities.

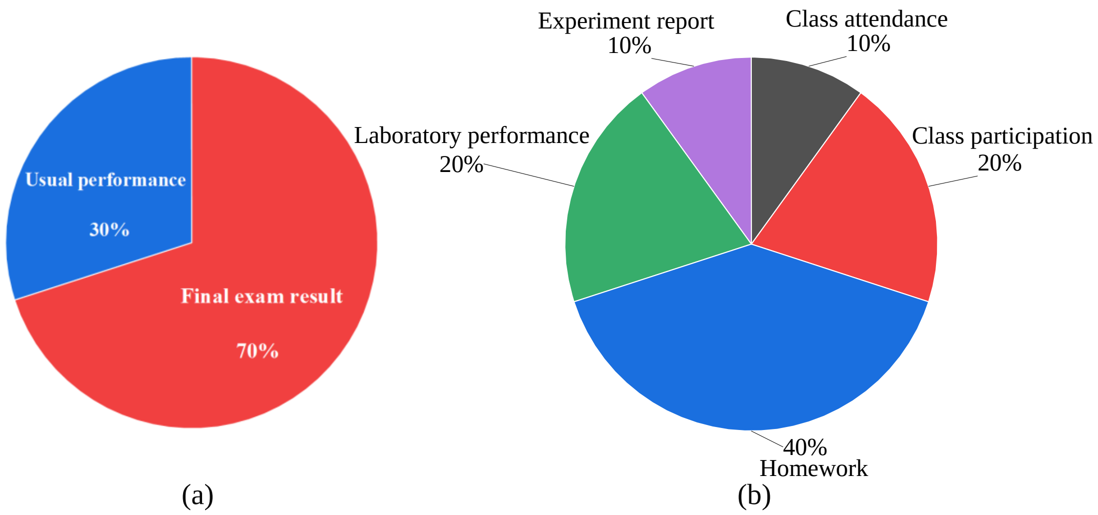


Figure 1: (a) Student's score composition of Mechanical Engineering Control Theory course, (b) Composition proportion of usual performance assessment.

The total course score of students is composed of two parts: the final exam results (accounting for 70%) and the usual performance (accounting for 30%), as shown in Figure 1(a). The final exam mainly assesses the professional theoretical knowledge in the course, using various question types such as choice questions, true/false questions, fill-in-the-blank questions, calculation questions, analysis questions, drawing questions, and solution questions to comprehensively evaluate students' understanding and mastery of the knowledge points. The usual performance score mainly assesses the students' process-oriented learning situation, including five evaluation dimensions: class attendance (10%), class participation (10%), homework (40%), laboratory performance (20%), and experiment report (10%), as shown in Figure 1(b). The attendance and classroom participation of each student are recorded using intelligent teaching and learning software. The five main parts of the course content assigned five homework assignments. Students can consolidate their understanding of the knowledge points by completing the homework. During the 52 class hours of this course, students have four opportunities (8 class hours) to enter the school's computer room to conduct MATLAB-assisted simulation experiments. The teacher first teaches the students how to use MATLAB for control system analysis, and then the students do independent programming exercises. The teacher can observe and evaluate the students' situation in conducting the simulation experiments and provide guidance. Students complete the relevant experiment reports around four tasks: the mathematical model of the control system, time-domain analysis, frequency-domain analysis, and stability analysis.

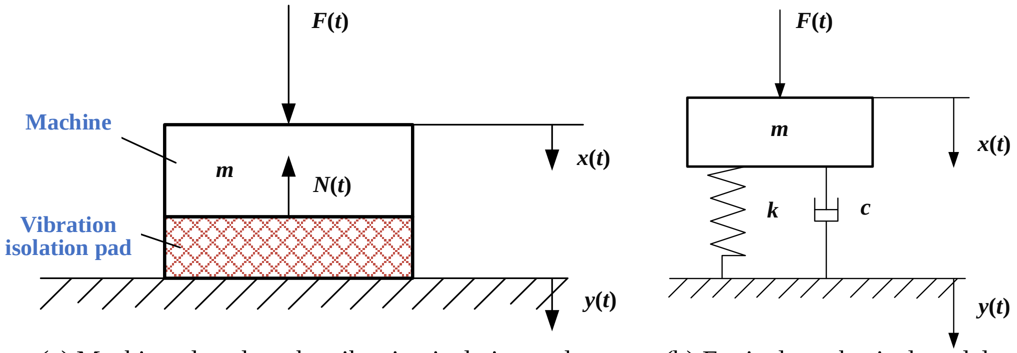
3. Teaching Innovation Methods

3.1. Integrating Ideological and Political Education in Classroom Teaching

Throughout the teaching of Mechanical Engineering Control Theory course, efforts should be made to strengthen curriculum-based ideological and political education, actively integrating ideological and political education in the teaching of mechanical engineering control theory. Teachers should exert a subtle yet positive influence on students by demonstrating values and scholarly ideals. When teaching the history of control theory, teacher introduce the story of Xuesen Qian, China's renowned scientist in control science field and the "Father of China's Aerospace". Share his arduous journey back to China from the United States and his groundbreaking contributions to China's aerospace industry [4,5]. Such role models can help instill a sense of patriotism in students and strengthen their responsibility and mission to serve the nation through science and technology. When explaining how the principle of negative feedback closed-loop control enhances system accuracy, teachers introduce some real-world control systems, such as the BeiDou Navigation Satellite System, autonomous train control systems for high-speed railways, and aircraft autopilot systems. By analyzing the automatic control principles in these systems, one can emphasize the course's importance in practical engineering applications and further motivating students to engage actively in their studies. Ultimately, by integrating ideological and political education in classroom teaching, we aim to achieve an organic synthesis of students' knowledge acquisition, professional development, personal values, and national spirit. This approach strives to enhance the social responsibility and comprehensive qualities of contemporary university students.

3.2. Combining theoretical knowledge with engineering projects

Many theoretical concepts in the Mechanical Engineering Control Theory course are abstract and difficult to grasp, so teachers present theoretical contents in isolation hinders students' comprehension and mastery. Classroom teaching should advocate for problem-based, case-based, and engineering problem-driven teaching methods, implementing engineering projects-based learning. By consistently incorporating the analysis and explanation of multiple engineering cases, and organically integrating theoretical knowledge with practical engineering projects, students can master fundamental theories and methods while simultaneously understanding the practical applications of theoretical knowledge. This facilitates a gradual transition in teaching methodology from knowledge transmission to competency cultivation. Furthermore, introducing engineering projects can inspire students research interest, stimulate innovative thinking, and cultivate students with solid theoretical grounding and well-rounded development in abilities.



(a) Machine placed on the vibration isolation pad (b) Equivalent physical model

Figure 2: The impulse response curves and step response curves plotted in MATLAB.

The following is a practical engineering project introduced when explaining the mathematical model of a control system. Vibration isolation of machinery is required in engineering applications. On one hand, this reduces vibration and noise generated during equipment operation; on the other hand, minimizing machine vibration decreases wear and fatigue on components and extends the equipments' service life. For the machine placed on the vibration isolation pads shown in Figure 2(a), please provide the corresponding mathematical model to help analyze the system's dynamic performance. First, the force analysis of machine is performed and the dynamic equation is:

$$m\ddot{x}(t)+N(t)=F(t) \tag{1}$$

If the vibration isolation pad is approximated as a combination of a damper and a spring, then:

$$N(t)=c\dot{x}(t)+kx(t) \tag{2}$$

Therefore, the dynamic equation of the system is:

$$m\ddot{x}(t)+c\dot{x}(t)+kx(t)=F(t) \tag{3}$$

Perform Laplace transformation on both sides of the above equation, and the transfer function of the system is obtained as:

$$G(s)=\frac{X(s)}{F(s)}=\frac{1}{ms^2+cs+k} \tag{4}$$

3.3. MATLAB-aided Simulation Experiments Teaching

The Mechanical Engineering Control Theory course mainly introduces the classical control theory knowledge, involving a large amount of mathematical knowledge, hard system performance analysis, and complex diagram drawing. In the classroom teaching, the basic concepts, theoretical derivations and analysis methods will be given a preliminary explanation. While the teaching contents related to the complex mathematical models, time-domain analysis, frequency-domain analysis, stability analysis, etc. can all be carried out based on MATLAB. MATLAB with functions of efficient numerical calculation and graphic processing is a powerful tool for control system analysis[6]. This teaching innovation focuses on MATLAB-assisted simulation experiments of control systems, which can not only help students deepen their understanding of control theory, but also enhance their intuitive perception and increase their interest in learning.

3.3.1. Commonly used MATLAB functions

To help students quickly master the method of analyzing system performance using MATLAB functions, the commonly used MATLAB functions in control system analysis are summarized and organized in Table 1. This helps students deepen their understanding of the mechanical engineering control theory knowledge taught in classroom and further stimulates their interest in learning.

Table 1: Commonly used MATLAB functions for analyzing the control systems.

Teaching Chapter Contents	MATLAB functions
Mathematical models of control system	tf( ), conv( ), zpk( ), residue( ), tf2zp( ), zp2tf( ), series( ), parallel( ), feedback( ), cloop( ), laplace( )
Time-domain analysis of control system	impulse( ), step( ), lsim( )
Frequency-domain analysis of control system	logspace(), nyquist( ), bode( )
Stability analysis of control system	roots( ), pzmap( ), margin( )

3.3.2. Time-domain analysis based on MATLAB functions

The purpose of conducting time-domain analysis of a system is to examine the dynamic performance characteristics such as stability, accuracy, and response speed. However, it is challenging to quickly plot precise time response curves for first-order systems, second-order systems, and higher-order systems under impulse signal, step signal, and arbitrary input signals during classroom teaching of this content. This difficulty hinders students' understanding of time-domain analysis related knowledge point. By employing MATLAB functions, we can not only rapidly generate accurate time response curves but also visually demonstrate how time response curves vary with different system parameters. This approach significantly enhances students' comprehension of how system parameters influence system performance.

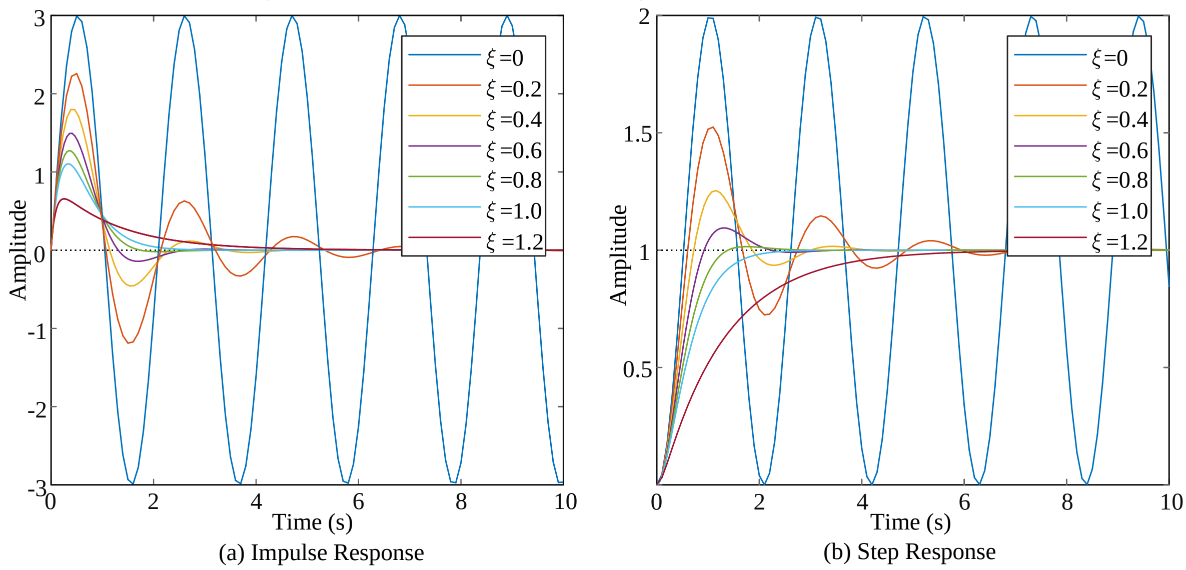
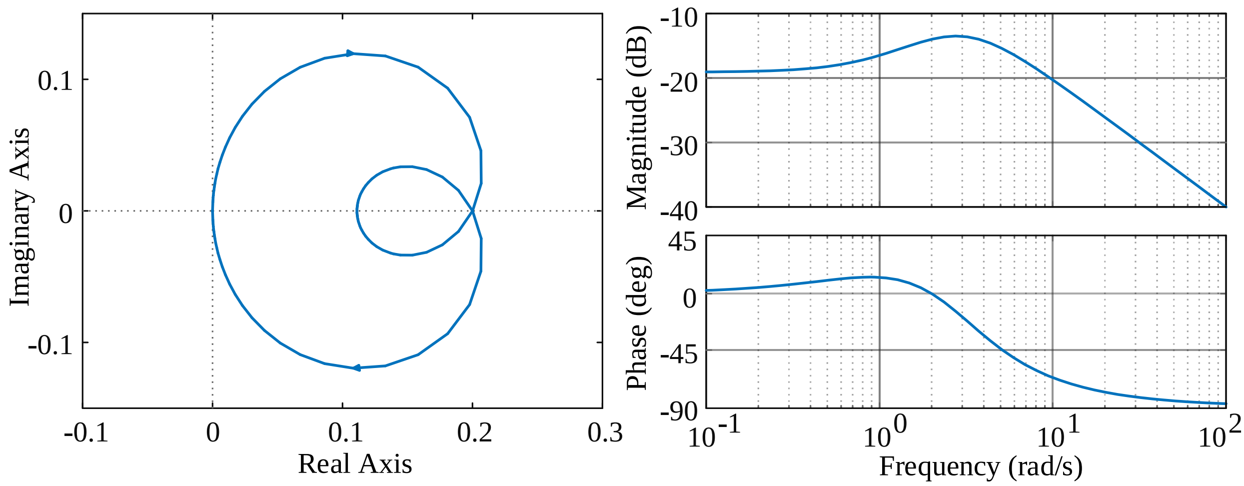


Figure 3: The impulse response curves and step response curves plotted in MATLAB.

For example,for the second-order system $G(s)=\frac{\omega_n^2}{s^2+2\xi\omega_n s+\omega_n^2}$, $\omega_n=3$, MATLAB can be utilized to plot the impulse response curves and step response curves for damping ratios ξ of 0, 0.2, 0.4, 0.6, 0.8, 1.0, and 1.2, as shown in Figure 3(a) and (b). From these time response curves, one can visually observe changes of the dynamic performance under different damping ratios. In addition, time-domain performance metrics such as rise time, peak time, maximum overshoot, settling time, and number of oscillations can be derived from these curves.

3.3.3. Frequency-domain analysis based on MATLAB functions

The frequency-domain analysis method evaluates the steady-state response of the system under harmonic inputs at different frequencies. By examining the frequency characteristic $G(j\omega)$, one can assess the system's stability and stability margins, and select system parameters for system compensation to achieve desired performance. The frequency characteristic $G(j\omega)$ is a function of the frequency ω, the common graphical representations of frequency characteristics include the Nyquist diagram and Bode diagram. In classroom teaching, the asymptotes of frequency characteristic curves are often approximated by sketching based on the magnitude and phase at specific key frequencies, though this process tends to be cumbersome and error-prone for students. Similarly, MATLAB can efficiently generate frequency characteristic curves that demonstrating their relationship with frequency variations, which offers intuitive visualization, convenience, speed, and accuracy. For instance, MATLAB can be used to plot the Nyquist diagram and Bode diagram for a second-order system $G(s)=\frac{s+1}{s^2+5s+9}$, as illustrated in Figures 4(a), (b).



(a) Nyquist Diagram (b) Bode Diagram

Figure 4: The Nyquist diagram and Bode diagram plotted in MATLAB.

3.3.4. Stability analysis based on MATLAB functions

The system stability refers to the ability to restore the original equilibrium state after being disturbed. It is a prerequisite for the normal operation of the system and can ensure its dynamic performance, prevent runaway and ensure safe operation. The system stability depends on the roots of the characteristic equation of the closed-loop system, but it is very difficult to directly solve the characteristic roots in high-order characteristic equations. MATLAB can provide a fast and accurate method for determining the stability of the system. For a system with the closed-loop transfer function of $G(s)=\frac{3s^4+2s^3+s^2+4s+2}{3s^5+5s^4+s^3+2s^2+2s+1}$, MATLAB can directly draw the pole-zero map, as shown in Figure 5, in which zeros are represented by the symbol "○" and poles by the symbol "×". It can be seen that there are two poles in the right half-plane, so it can be determined that this system is unstable.

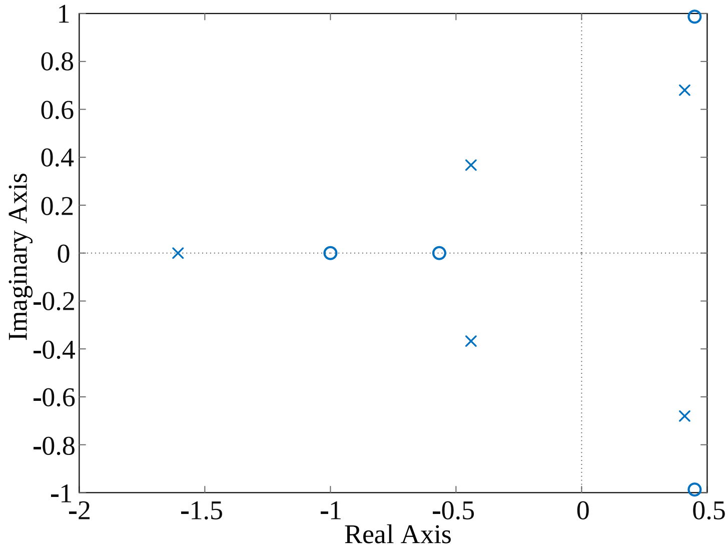


Figure 5: Pole-Zero map.

4. Conclusions

With the rapid development of modern manufacturing, the demand for innovative multidisciplinary engineering talents is growing increasingly strong. To better cultivate well-rounded professionals with solid foundational knowledge and innovative practical abilities, it is imperative to reform the teaching of the core undergraduate mechanical engineering course Modern Mechanical Control Engineering. This paper explores multidimensional teaching innovation methods, including diversified assessment methods, integrating ideological and political education in classroom teaching, combining theoretical knowledge with engineering projects, and MATLAB-aided simulation experiments teaching. These innovation methods help stimulate students' research interest, inspire their innovative thinking, and enhance their practical skills.

References

[1] Wang L.J., Li H., Lu X., Che H. and Yang Z.Z. (2021) Research on Ideological and Political Education Based on the Course of Mechanical Control Theory. Advances in Educational Technology and Psychology, 5,127-132.

[2] Deng A.T., Zhang Y., Zhang G.P., Wang Z.L. (2022) Research on Teaching Reform of Online Course Resources Construction Based on 'Modern Control Theory'. Curriculum and Teaching Methodology, 5, 122-125.

[3] Lu J.R., Zhou J. (2025) Construction and Improvement of the Computer-Aided Design Technology Course for Mechanical Design, Manufacturing, and Automation under the Framework of "Emerging Engineering Education". Advances in Educational Technology and Psychology, 9: 127-134.

[4] Cai, P., Chang, T. (2020) The Exploration of Improving Practical Teaching Effectiveness of Ideological and Political Theory Course with "Five Unification". Open Journal of Social Sciences, 8, 1402-1406.

[5] Tian X. (2025) Exploration of Teaching Innovation and Practice of Ideological and Political Courses in Colleges and Universities under the Background of the New Era. Advances in Educational Technology and Psychology, 9, 44-47.

[6] Shen H.M., Luo Y.J. (2023) Practical Exploration of the Course Control Engineering Fundamentals for Mechanical Engineering. Curriculum and Teaching Methodology, 6, 92-95.