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Teaching Discussion Based on Mechanical Dynamics Simulation Teaching Case

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ABSTRACT

Dynamics of mechanical system has received more and more attention in the undergraduate and postgraduate course of mechanical specialties. And how to improve the quality of education through case teaching has become a mutually concerned subject of teaching methods reform. In view of shortage of combination of theory and practice in current mechanical dynamics teaching, through a concrete example of dynamics modelling and simulation with Simulink of a propelling shafting-hull coupled vibration system, the paper makes a discussion about the fundamental work of case teaching, i.e. the design and writing of novel teaching cases, including synthesizing the basic problems and methods of dynamics with practical engineering cases, transforming complicated engineering system into mechanic model, choosing study breakthrough point and analysis key point, constructing an integrated environment of modelling, simulation and analysis of dynamical system by theoretical analysis and software aided calculation, etc.. And the problem and its resolution of practical complicated flexible coupled dynamics system is demonstrated in classroom via visualized simulation.

Keywords: *Dynamics of mechanical system, Teaching methods reform, Teaching case design, Complicated flexible coupled system, Simulink, Padé approximation.*

1. GENERAL SITUATION OF TEACHING RESEARCH ON "MECHANICAL DYNAMICS" AND CASE TEACHING

Modern science and engineering technology pose a large number of dynamics and kinematics problems of complex systems, so mechanical dynamics has received more and more attention in undergraduate and graduate education of mechanical majors.

The teaching of traditional mechanical dynamics courses has long been a teacher-centered, or classroom-centered, or textbook-centered teaching model. The common phenomenon is that although teachers have completed the teaching of theoretical knowledge, students always have an abstract and empty feeling after learning. Although some students can achieve good results in exams, they still cannot solve practical problems. The characteristic of the mechanical dynamics course is that it not only contains a large amount of mathematics and mechanics deduction, but also has a lot of intersection with many courses or knowledge such as mechanical principles, mechanical design and manufacturing, so it increases the difficulty of teaching for teachers and students. Increasing practical teaching links and increasing the interest of the courses are good ways to improve the teaching effect, but more attention should be paid to guiding the arrangement of teaching content and the design of teaching models with modern educational concepts to promote students' independent thinking and research ability[1].With the flexibility and diversification of educational forms, teaching aids and scientific research aids, the attempt to reform the teaching content, methods and means of mechanical dynamics is one of the exploratory topics in education and teaching research. Reference[2] introduces how to strengthen students' ability to use related professional software, and combine engineering examples to cultivate students' ability to discover, analyze, and solve problems, and to enhance students' innovative ability; establish a library of exercises and a teaching website to further improve the quality of teaching. Reference[3,4]proposed a variety of teaching methods such as the combination of teacher lectures and student group discussions, the combination of teaching plans and network teaching resources, the combination of theoretical calculations and software analysis, etc., in order to improve students' learning awareness and participation, and improve the teaching quality of the "mechanical dynamics" course. Reference [5] In order to meet the needs of the German ASIIN assessment major, it explores teaching methods and multi-modal assessments that combine classroom practice with practice, in order to gradually transform students from passive to active pursuit of knowledge and accumulate more vision and experience in dealing with practical problems, to lay the foundation for faster adaptation to the project when working or continuing to study in the future, train students with European engineer qualifications. Reference [6] introduced the application of the flipped classroom teaching model, as well as mobilizing the subjective initiative of students through pre-class-online autonomous learning, in-class-offline interactive seminars, after-class-online and offline Q&A counseling, and combined with case teaching, achieve good teaching results.

Case-based teaching originated from Harvard University, at first it was through targeted case explanations to guide students to discuss and analyze specific practical problems [7].Cases from engineering practice are often comprehensive. Students are required to use various knowledge and skills they have learned, consult and discuss, so that students can sort out a set of methods that suit their own problems, and they need to be able to analyze problems and solve practical problems independently [8].Case-based teaching is integrated into the teaching of different courses. The teaching staff follows the requirements of the teaching purpose and uses cases as the basic material to introduce students into specific real situations. Through exchanges and interactions, equal dialogues and discussions, the focus is on cultivating learners' sense of critical reflection and group cooperation ability, and encourage students to fully understand the complexity, variability, diversity and other attributes of the problem. Case-based teaching can especially be used as a targeted teaching method to solve some of the long-standing problems in mechanical dynamics teaching, such as abstraction and inability to apply what has been learned, but it is still in the stage of exploration and practice [9, 10].

2. "MECHANICAL DYNAMICS" TEACHING CASE DESIGN

2.1. Design Requirements for Teaching Cases

Focusing on the combination of theory and practice is the main feature of the case teaching method, and its core lies in the selection and discussion of cases. Teachers choose typical, complex, and knowledge-oriented cases in the classroom, and then discuss the knowledge points and scope of knowledge to be taught through case discussions, which can make teaching more attractive, and students can overcome their own inertia and take out more His patience is used to concentrate, actively use relevant theoretical knowledge and skills to flexibly deal with corresponding case problems. Case design is a basic work, and making excellent teaching cases is a prerequisite for the success of case-based teaching methods.

Based on the foregoing analysis, the teaching case design should follow the following guidelines:

• On the premise of meeting the teaching goals, the selection of cases is close to the frontiers of scientific research or engineering technology. They are often scientific research topics from the discipline or adjacent disciplines, and keep pace with the times in terms of teaching content; classic theories change slowly, but classics The case is not static, but is closely following the steps of scientific research.

• The focus of case writing is to describe the key parts of knowledge to be imparted and the scope of necessary cross-parts through specific analysis of engineering cases, reflecting the teaching purpose of focusing on integrating theory with practice.

• Apply the most popular and popular research aids and teaching aids such as multimedia, ANSYS, MATLAB and other simulation software. For example, in the teaching of mechanical dynamics, the abstract mathematical expression of dynamics is converted into intuitive graphics and images through various auxiliary means, and applied to teaching cases [11, 12].

2.2. Designing a Teaching Case of "Mechanical Dynamics" Based on a Complex Elastic Coupling System

Complex engineering cases are suitable for concretely embodying the complexity of actual engineering and the relevance between different subject theories, and accurately sketching out a broad range of knowledge. The following takes "Analysis of the coupled vibration characteristics of a ship's propulsion shafting and hull" as an example to discuss the design method of the "Mechanical Dynamics" teaching case.

2.2.1. The Engineering Background and Scientific Research Background of the Case

The main engine-propulsion shafting-propeller system shown in Figure 1 is a power propulsion system device commonly used in various ships. Due to the crucial position of the propulsion shafting in the safety of ship navigation, there are high requirements for its design, installation, maintenance, etc. and the vibration characteristics and control of the shafting are an important content. The vibration of the propulsion shaft system has two adverse effects on the navigation performance and safety of ships. One is the functional damage to the mechanical structure and system, such as fatigue damage to rotating parts such as bearings, shaft alignment failure, tearing of high elastic rubber couplings, coupling bolts cut off, and local shaft section heating , Drive shaft fracture, etc. Another problem is that the vibration of the propulsion shaft system is transmitted to the hull through radial bearings, thrust bearings and other connecting frames, and causes vibration and noise of the hull. The influence of the vibration of the propulsion shafting on the noise radiation characteristics of the hull can be confirmed according to the results of some field tests, and it is still an important subject in the submarine stealth technology.

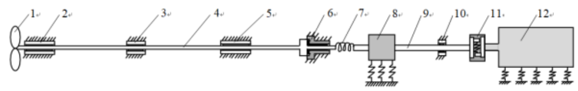


Figure 1 Schematic diagram of a certain propulsion shafting structure

Mechanical vibration has its own engineering application value, it is also included in the teaching of mechanical dynamics as the theoretical basis of mechanical elastodynamics. Taking the shaft vibration problem as a case, it can comprehensively demonstrate the basic concepts and theoretical applications of mechanical dynamics, such as excitation and response, dynamic modeling, subsystem decomposition, dynamic equations of continuous elastic bodies, etc.

2.2.2. System Theory Model

The complex elastic coupling system is divided into subsystems according to the mechanical structure and power transmission relationship. Fig.2 is an exploded description of the longitudinal excitation transfer relationship of the system in Fig.1, where F_a is the longitudinal excitation of the propeller, $F_P/F_A/F_{AH}$represent the dynamic forces between the propeller, thrust shaft, thrust bearing (oil film), and hull structure, respectively. Propeller excitation also includes lateral excitation and torque excitation. To reduce the length of the narrative, take the transmission of longitudinal excitation as an example.

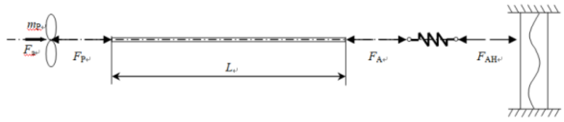


Figure 2 Power transmission of shaft-hull coupling longitudinal vibration system

It is the basic method of mechanical vibration and mechanical dynamics to study and analyze various mechanical dynamics problems by establishing mechanical models. It is difficult to learn to abstract various dynamic systems in engineering into mechanical models and mathematical models. When designing the teaching case, in the process of establishing the dynamic equation with reference to Fig.2, the different simplified processing methods of the mechanical model should be discussed, for example:

• The propeller is simplified as a rigid body or treated as an elastomer.

•The thrust axis is simplified as a rigid body or treated as an elastic body; when treated as an elastic body, it is simplified as the difference between a uniform rod or a variable cross-section rod.

• How to determine the oil film stiffness of the thrust bearing?

• The hull structure is treated as a rigid body or treated as an elastic body. How to properly simulate the elasticity of the hull structure in order to evaluate its influence on the longitudinal vibration of the entire propeller-shaft-hull coupling system?

• The connection between the above issues and the objectives of the project.

2.2.3. Solution and Visual Simulation of Motion Differential Equation

Equations(1)~(4)are one of the theoretical modeling schemes of the system in Fig. 2, in which the propeller, thrust shaft, and thrust bearing are respectively simplified as rigid bodies (massm_P), uniform rods (density ρ, length L, tensile stiffness E_A) and linear spring (stiffness k_A). The structural characteristics of the hull are described by the continuous elastic body's modal coordinate equation (modal mass M_i, modal frequency ω_i, damping loss factor ξ_i, mode function U_{Hi}); *u(x, t)* and u_H represent the vibration displacement functions of the thrust shaft and the thrust bearing base, respectively.

$$m_P\ddot{u}\left(0,t\right)+c_P\dot{u}\left(0,t\right)+F_P=F_a \tag{1}$$

$$\rho A\ddot{u}-EA\left(\partial^2u/\partial x^2\right)=-F_P\delta\left(x\right)-F_A\delta\left(x-L\right) \tag{2}$$

$$F_A=F_{AH}=k_A\left[u\left(L,t\right)-u_H\right] \tag{3}$$

$$u_H=\sum_{i=1}^{\infty}U_{Hi}q_i\ ,\ \ddot{q}_i+2\xi_i\omega_i\dot{q}_i+\omega_i^2q_i=F_{AH}U_{Hi}/M_i \tag{4}$$

Using the Fourier transform to solve the above differential equations is a commonly used method, but the complicated theoretical deductions in the classroom often damage the interest of many students. As far as teaching is concerned, the ideal situation should be to combine the solution of dynamic equations with visual simulation, and to guide students to complete dynamic simulation analysis on their own. For this reason, according to the system power transmission relationship in Fig. 2 and formulas (1)~(4), the transfer function model is established as shown in Fig. 3. The transfer function of each link can be transformed by Laplace transform to formula (1)~(4) And we get the following.

$$G_{\mathrm{P}}(s)=\frac{1}{m_{\mathrm{P}}s^2+c_{\mathrm{P}}s} \tag{5}$$

$$\begin{cases} G_{\mathrm{FF}}(s)=\dfrac{2\exp(-Ls/a)}{\exp(-2Ls/a)+1}, G_{\mathrm{FU}}(s)=\dfrac{EAs}{a}\dfrac{\exp(-2Ls/a)-1}{\exp(-2Ls/a)+1} \\ G_{\mathrm{UF}}(s)=-\dfrac{a}{EAs}\dfrac{\exp(-2Ls/a)-1}{\exp(-2Ls/a)+1}, G_{\mathrm{UU}}(s)=G_{\mathrm{FF}}(s) \end{cases} \tag{6}$$

In the above formula, $a=\sqrt{E/\rho}$.

$$Y_{\mathrm{A}}=\sum_{i=1}^{\infty}\frac{U_{\mathrm{H}i}^2}{M_i\left(s^2+2\xi_i\omega_i s+\omega_i^2\right)} \tag{7}$$

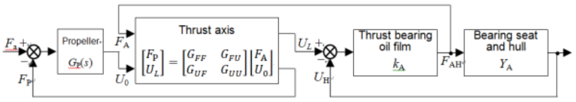
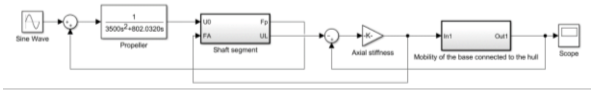
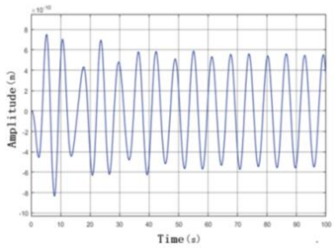


Figure 3 Shafting longitudinal excitation transfer function model

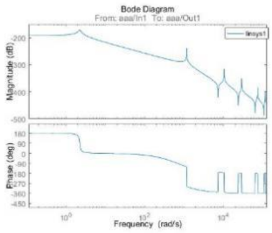
This case uses the transfer function model. One of the reasons is that the model in the form of a block diagram is visual and intuitive. The second reason is that the transfer function model can be directly imported into Simlink as a simulation model for system dynamic simulation, so that students can experience complex dynamics problems firsthand. The process from project planning to the establishment of theoretical models and numerical simulation analysis.



(a) Simulink simulation model



(b) Time domain diagram of longitudinal displacement response under sinusoidal excitation



(c) Bode diagram of the system transfer function

Figure 4 Simulink simulation model and results example

The model can be used to analyze and evaluate the dynamic characteristics of the system and visualize the results, for example:

• The main factors affecting the fundamental frequency of the system;

• The influence law of shafting structure size, Oil film stiffness of thrust bearing,bearing seat and hull impedance characteristics on system power transmission characteristics;

• The influence of nonlinear factors in the system.

Finally, regarding the Simlink simulation software environment and its application in case-based teaching, there have been some related documents that have been discussed, but it is rare to use Simlink to establish a dynamic simulation model of a complex coupled system containing a continuous elastic. It also often involves some more special conversion processing. A technical problem in Simulink modeling is that the delay function exp(-2*L*/a) appears in the denominator of formula (6). This function cannot be defined in Simulink. The solution is to expand it into a Padé expression [13].

$$\exp\left(\frac{-2Ls}{a}\right)=\frac{1-Ls/a+p_1(2Ls/a)^2-p_2(2Ls/a)^3+\cdots+p_i\left(-2Ls/a\right)^{i+1}+\cdots}{1+Ls/a+p_1(2Ls/a)^2+p_2(2Ls/a)^3+\cdots+p_i\left(2Ls/a\right)^{i+1}+\cdots} \tag{8}$$

Regarding formula (7) and formula (8) infinite series expression, take its finite term to approximate.

3. CONCLUSION

As a traditional course, mechanical dynamics has certain stability in the content of basic theory teaching, but there is also a large room for improvement in the organization of teaching content and teaching mode.The broadness and comprehensiveness of the knowledge of the mechanical dynamics course have brought greater difficulties for students to learn and apply the knowledge of this course. Obviously, teaching case writing is a basic work.The writing of new case-based teaching plans should focus on the integration of basic dynamics theories and methods into specific engineering problem cases, select typical engineering or scientific research cases and appropriate experimental teaching cases based on the training objectives of the curriculum.While paying attention to basic theoretical education, it also highlights the mutual transformation of physical models and mechanics models, the combination of complex engineering examples and typical exercises, and the mutual assistance of theoretical calculations and software analysis, to change the current situation of insufficient combination of theory and practice in mechanical dynamics teaching.

The case in the article has a certain degree of complexity, but the related analysis modeling method is still classic. The Simulink simulation modeling method has a certain representativeness in the field of visual modeling and simulation [14]. Similar simulation software is also Including MATLAB, ADAMS, ANSYS, etc. The advantages of these simulation software, for example, a rich and expandable library of predefined modules, simple and intuitive parameter settings, simple modeling process based on mouse operation, interactive graphics editor to combine and manage intuitive module diagrams, Graphical debugger and profiler to check simulation results, etc. The application of simulation software is integrated into the teaching case to provide an integrated environment for dynamic system modeling, simulation and comprehensive analysis, and the simulation results of the system can be seen immediately in the classroom. After students have mastered the relevant skills and ideas, they can learn to solve the simulation problems of similar complex systems, which will be of great help to the future independent topic writing papers and related technical work after graduation. In addition, mechanical dynamics as a subject involves a large number of engineering problems, and it is often impossible to display objects or implement experiments in teaching. Combining the analytical theoretical model with the application of mechanical dynamics simulation software in the writing of teaching cases can make up for the lack of experimental conditions. Using engineering software in the case to show the different knowledge points of the course and compare it with the theoretical results will strengthen the students' ability to apply the knowledge they have learned to solve practical problems.

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