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COMPOSITION AND SOLUTION OF EQUATIONS OF MOTION OF DYNAMIC MODELS" IN THE DISCIPLINE THEORY OF MECHANISMS AND MACHINES

Аннотация: В статье обсуждены вопросы касающихся составлению и решению уравнений движения динамических моделей. Даны рекомендации по эффективным методам обучения при изучении составления уравнений движения и использование наглядных материалов в объяснении динамических моделей для улучшения понимание и восприятие материала. Даны сравнения и интеграция нескольких методов решения уравнений движения, которые зависят от условий задачи и типа движения.

Ключевые слова; динамическая модель, теория механизмов и машин, механическая система, уравнения движения, компонент системы, валидация модели, методика обучения, кросс-дисциплинарный подход, MATLAB, Simulink, Python, интерактивные задания, тесты.

Abstract: The article discusses issues related to the composition and solution of equations of motion of dynamic models. Recommendations are given on effective teaching methods when studying the composition of equations of motion and the use of visual materials in explaining dynamic models to improve understanding and perception of the material. Comparisons and integration of several methods for solving equations of motion are given, which depend on the conditions of the problem and the type of motion.

Keywords: dynamic model, theory of mechanisms and machines, mechanical system, equations of motion, system component, model validation, teaching methods, cross-disciplinary approach, MATLAB, Simulink, Python, interactive tasks, tests.

INTRODUCTION . The discipline "Theory of Mechanisms and Machines" is of great importance in the training of bachelors in technical fields. Here are some key aspects of its importance: the discipline provides fundamental knowledge about the principles of operation of mechanisms and machines, which is the basis for understanding more complex engineering problems; students learn to design mechanisms, analyze their operation and identify possible problems. This is critically important for the development of new technologies and improvement of existing ones; the knowledge gained in this discipline is applicable in various fields, such as mechanical engineering, robotics, automation and other engineering specialties; the study of the theory of mechanisms and machines develops analytical thinking and the ability to solve complex problems, which is necessary for successful engineering practice; the discipline includes laboratory work and projects, which allows students to apply theoretical knowledge in practice and develop skills in working with modern equipment; understanding the principles of operation of mechanisms allows graduates to be more prepared for the implementation of innovative solutions in industry; working on projects in a group develops teamwork and communication skills, which is important for future professional activity [1].

Overall, the course "Theory of Mechanisms and Machines" provides the knowledge and skills necessary for a successful career in engineering and promotes critical thinking and a creative approach to solving technical problems.

A dynamic model of a mechanical system is a mathematical representation that describes the behavior of a mechanical system over time [2]. It takes into account the interactions between the

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components of the system, their movements, and the forces acting on them. The main aspects of a dynamic model include:

1. Equations of Motion: The model is usually based on Newton's laws (or other principles of mechanics) and includes equations that describe how forces and moments affect the motion of objects.

2. System states: The dynamic model describes the state of the system at each moment in time, including parameters such as position, velocity, and acceleration.

3. System parameters: The model takes into account physical parameters such as mass, stiffness, damping and geometry of components.

4. External influences: The model may include the influence of external forces or conditions (e.g. loads, friction, vibrations).

5. Numerical methods: Numerical methods such as the Euler method or the Runge-Kutta method are often used to solve the equations of motion, which allows modeling the dynamic behavior of the system.

6. Application: Dynamic models are used for stability analysis, design of control systems, forecasting the behavior of mechanisms and machines under various conditions.

Ultimately, a dynamic model of a mechanical system allows engineers and scientists to study and optimize the performance of mechanical systems, predict their behavior, and develop new technologies.

The formulation of equations of motion for a dynamic model involves several key steps[3]. The main ones are:

1. Definition of the system and its boundaries:
- Select the objects that will be part of the model.
- Define the boundaries of the system to understand which interactions to include.

2. Select coordinates:
- Define a coordinate system to describe the position of objects (e.g. Cartesian or polar coordinates).
- Select generalized coordinates that are convenient to use to describe the state of the system.

3. Definition of forces and moments:
- Identify all the forces involved (gravitational, elastic, frictional, etc.).
- Take into account moments acting on objects (for example, from rotation).

4. Application of Newton's laws or other principles of mechanics:
- Use Newton's second law (F = ma) to formulate equations of motion.
- In the case of complex systems, one can apply the d'Alembert principle or use the Lagrange method.

5. Drawing up equations of motion:
- Write down the equations that describe the dynamics of the system. These may be second-order differential equations for displacements or systems of equations for several objects.

6. Taking into account restrictions:
- If the system has constraints (e.g., connections between objects), add them to the model. This can be done using constraint equations or by using generalized coordinates.

7. Verification and validation of the model:
- Check the equations for physical validity and consistency.
- Compare the results with experimental data or known solutions to confirm the correctness of the model.

8. Numerical solution:
- If the equations are complex, use numerical methods to solve them (for example, Euler's method, Runge-Kutta method).

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By following these steps, one can effectively formulate the equations of motion for a dynamic model of a mechanical system.

TEACHING **METHODOLOGY :**

When learning how to formulate equations of motion, there are several effective teaching methods that can be used:

1. Practical tasks:

- Solving real problems helps to consolidate theoretical knowledge. Let's start with simple problems and gradually move on to more complex ones.

2. Group training:

- Discussing problems and solutions with classmates or in study groups can help you better understand the material and see different approaches to solutions.

3. Lectures and seminars:

- Attending lectures and seminars, where teachers explain the theory and show examples, helps to assimilate the material on a deeper level.

4. Modeling:

- Using simulation software (such as MATLAB, Simulink, or Python) allows you to visualize movement and experiment with system parameters.

5. Independent study:

- Reading textbooks and research articles, watching video tutorials and online courses can deepen your understanding of the topic.

6. Feedback:

- Receiving feedback from teachers or more experienced colleagues helps to identify mistakes and improve skills.

7. Interactive platforms:

- Using online platforms that offer interactive assignments and tests can make the learning process more engaging and effective.

8. Cross-disciplinary approach:

- Studying related fields such as physics, mathematics and engineering can provide a more complete understanding of the dynamics of systems.

9. Project work:

- Participation in projects related to dynamics allows you to apply knowledge in practice and develop teamwork skills.

By combining these methods, one can gain a deeper understanding and confidence in formulating the equations of motion.[4]

Using visual aids to explain dynamic models can greatly improve understanding and comprehension of the material. Here are some ways to do this:

1. Graphs and charts: Visualizing data using graphs allows you to see the relationships between variables. For example, graphs of speed, acceleration, and time can help you understand how these quantities interact.

2. Models and mock-ups: Creating physical models (e.g. from paper or plastic) allows dynamic systems to be visually demonstrated. This can be useful for studying the motion of bodies or systems with several interacting parts.

3. Animations and Videos: Using animations and videos to demonstrate processes, such as objects moving under forces, helps to better understand dynamics. Platforms like YouTube offer a variety of educational videos.

4. Simulations: Software simulators (e.g. PhET) allow you to model dynamic systems in real time by changing parameters and observing the results.

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5. Infographics: Creating infographics that combine textual information and visual elements can help explain complex concepts more clearly.

6. Posters and Displays: Using posters with key formulas, laws and examples can serve as reference material during training.

7. Using interactive whiteboards: Using interactive whiteboards in the classroom allows teachers to draw diagrams and graphs in front of students, which encourages greater engagement.

8. Real-life cases: Using examples from everyday life (such as a car moving or a ball falling) helps connect theory with practice.

9. Laboratory Experiments: Conducting experiments in the laboratory using sensors and measuring instruments allows students to independently observe dynamic processes.

These methods can greatly increase students' interest in the topic and help them better understand the material.

The formulation of equations of motion is based on several key principles of physics[5]:

- First law (law of inertia): A body maintains its state of rest or uniform rectilinear motion until an external force acts on it.
- Second law: The acceleration of a body is proportional to the force acting on it and inversely proportional to its mass (F = ma).
- Third Law: For every action there is an equal and opposite reaction.
- In a closed system, the total energy (the sum of kinetic and potential) is conserved if no external forces act on the system.
- In a closed system, the total momentum is conserved, which is especially important during collisions and interactions between bodies.
- To describe motion with constant acceleration, special equations are used that relate the initial and final speed, acceleration, time and distance traveled.
- The correct choice of coordinate system (Cartesian, polar, etc.) is important for the correct description of the movement of objects.
- Movement is described by vector quantities (speed, acceleration, force), which allows us to take into account the direction of movement and interactions.
- In complex systems, mathematical modeling and approximations can be used to simplify analysis.

These principles help formulate equations that describe the motion of objects under different conditions.

4. Solving equations:

There are several methods for solving the equations of motion, which depend on the conditions of the problem and the type of motion. Here are some of them:

1. Analytical methods

- Kinematic equations: Used to solve problems with constant acceleration.

2. Graphical methods

- Plotting graphs of coordinates versus time, speed versus time, etc. This allows you to visually assess the movement.

3. Integration method

- Used to obtain equations of motion from Newton's laws.

4. Numerical integration method

- Used when an analytical solution is impossible. Numerical methods such as Euler's method or Runge-Kutta's method are used.

5. Lagrange method

- Used in mechanics for systems with several degrees of freedom. Allows one to write down the equations of motion through the Lagrangian.

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6. Hamilton's method

- A more general approach that uses the Hamiltonian to describe the dynamics of the system.

These methods can be combined depending on the complexity of the task and traffic conditions.

Students may encounter several major difficulties when solving the equations of motion:

1. Understanding the concepts:

- Lack of understanding of basic physical concepts such as speed, acceleration, distance and their relationships.
- Difficulty in distinguishing between uniform and uniformly accelerated motion.

2. Selecting the correct equations:

- Errors in choosing appropriate kinematic equations for a specific problem.
- Incorrect application of equations, especially in cases where acceleration changes.

3. Working with units of measurement:

- Problems with converting units (for example, from kilometers per hour to meters per second).
- Incorrect use of units, which may lead to erroneous results.

4. Graphical representation:

- Difficulties in interpreting graphs of coordinate versus time or velocity versus time.
- Incorrect reading of charts, which can affect the understanding of the movement.

5. Numerical methods:

- Difficulties in using numerical integration methods if an analytical solution is impossible.
- Errors in programming algorithms for numerical solutions.

6. Mathematical skills:

- Problems with mathematical calculations, such as solving quadratic equations or working with vectors.
- Lack of understanding of how to apply derivatives and integrals in the context of physics.

7. Complex systems:

- Difficulties in analyzing multi-connected systems or systems with several bodies.
- Understanding conservation laws (e.g. conservation of momentum or energy) in complex problems.

8. Visualization problems:

- Difficulty in visualizing the movement of objects in space.
- Lack of understanding of how different forces affect the movement of a body.

9. Psychological factors:

- Fear of difficult tasks or lack of confidence in their knowledge can prevent students from solving problems effectively.

These difficulties can be overcome through practice, additional explanations, and the use of various learning resources.

The following evaluation criteria can be used to analyze students' practical work:

1. Contents:

- Completeness and accuracy of the data provided.
- Compliance of the work with the stated topic and objectives of the assignment.
- Depth of analysis and justification of conclusions.

2. Methodology:

- Using correct methods and approaches to solve the problem.
- Justification for the choice of methods and tools.
- Ability to think critically and analyze.

3. Structure of the work:

- Logicality and consistency of presentation of the material.

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- Having a clear introduction, main body and conclusion.
- Correct design of sections and subheadings.

4. Quality of execution:
- Accuracy of calculations and execution of experimental procedures.
- The level of accuracy in presenting the results (graphs, tables, etc.).
- Compliance with scientific design standards (references, bibliography).

5. Originality:
- Unique approach to solving the problem.
- Creativity in presenting results or proposing new ideas.

6. Communication skills:
- Clarity and precision of presentation of thoughts.
- Ability to argue your point of view.
- Effectiveness of visual materials (if applicable).

7. Teamwork (if applicable):
- Participation of each group member in completing the task.
- Ability to cooperate and delegate responsibilities.

8. Reflection:
- Ability to analyze one's own mistakes and achieved results.
- Evaluation of the work process and identification of opportunities for improvement.

9. Execution time:
- Compliance with deadlines for completing the task.
- Effective time management during work.

These criteria will help to ensure an objective and comprehensive assessment of students' practical work, as well as to identify areas for further development and improvement.

The application of the theory of mechanisms and machines in industry is closely related to the formulation and solution of equations of motion, since these equations describe the dynamic behavior of mechanical systems [6]. Here are some key points that illustrate this connection:

- To analyze the operation of machines and mechanisms, it is necessary to create a mathematical model that includes the geometry, kinematics and dynamics of the system. Equations of motion allow us to describe how the elements of the mechanism interact with each other.
- Equations of motion help to determine the forces and moments acting on the elements of mechanisms. This is important for calculating the load on the parts, which allows preventing their destruction and ensuring the reliability of the machines.
- Creating and solving equations of motion allows engineers to optimize mechanism designs by selecting optimal parameters (e.g. dimensions, materials) to achieve the required performance and durability.
- Many mechanisms are subject to oscillatory motion. Equations of motion allow us to analyze these oscillations, which is important for ensuring the stability and safety of the machines.
- Modern industrial systems often use automated controls. Motion equations serve as the basis for developing control algorithms that ensure the accuracy and efficiency of the mechanisms.
- Modern CAD and CAE systems use equations of motion to simulate the behavior of mechanisms under various loads. This allows potential problems to be identified in advance and the project to be optimized before its implementation.
- In robotics, equations of motion are needed to plan the trajectories of robots, allowing them to perform tasks with high accuracy.

CONCLUSION

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Thus, the theory of mechanisms and machines based on the equations of motion is an important tool for the design, analysis and optimization of mechanical systems in industry.

In the field of mechanical engineering, there are many real-world examples of dynamic models used to analyze and design mechanisms. Here are a few:

1. Car suspensions:

- Dynamic models of vehicle suspensions help analyze the behavior of the vehicle on uneven roads. These models take into account the forces acting on the wheels, body and suspension, which allows you to optimize the comfort and control of the car.

2. Robotic manipulators:

- To control the movement of robotic manipulators, dynamic models are created that describe the kinematics and dynamics of their limbs. This allows for precise trajectory planning and control of the forces required to perform manipulations.

3. Transmission systems:

- In geared mechanisms (e.g. gearboxes), dynamic models are used to analyze torque and speed transmission. This helps in designing more efficient and reliable systems.

4. Crane installations:

- Dynamic crane models allow you to analyze the loads that occur when lifting and moving loads. This is critical to ensuring safety and preventing overloads.

5. Aircraft:

- Flight dynamics models are used to analyze the behavior of aircraft and helicopters in various flight modes. This includes the study of stability, maneuverability, and controllability.

6. Machine mechanisms:

- Dynamic models of machine tools (for example, lathes or milling machines) help to analyze vibrations and oscillations, which is important for achieving high precision machining of parts.

7. Pneumatic and hydraulic systems:

- Models of flow dynamics in such systems allow us to analyze the behavior of liquids and gases, which is critical for the design of pumps, compressors and other mechanisms.

8. Air conditioning systems:

- Dynamic models of HVAC (heating, ventilation and air conditioning) systems help analyze the distribution of temperatures and air flows in rooms, which allows optimizing their operation.

These examples demonstrate the importance of dynamic models in ensuring the reliability, efficiency and safety of various machines and mechanisms in mechanical engineering.

These questions will help you test your understanding of the topic and identify key aspects of the teaching methodology.

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