Ministry of Education and Science of Ukraine
Sumy State University

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ROTOR MACHINERY DYNAMICS

Control Tasks

Sumy
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2022

Pavlenko I. V. Rotor machinery dynamics: Control tasks [electronic version] / I. V. Pavlenko – Sumy : Sumy State University, 2022. – 16 p.

Recommended by the Department of Computational Mechanics named after Volodymyr Martsynkovskyy (minutes No. 5 of 21.12.2022).

Contents

Topic 1. The fundamentals of rotor dynamics

A simple conservative single-mass model of rotor dynamics. Direct synchronous precession. A self-balancing phenomenon. Equation of a motion for a single-mass model of the unbalanced rotor. Considering the external friction. Kinematics of rotating rotor's precessions. Equation of rotor dynamics considering the anisotropy of elastic forces. Loss of dynamic stability. Forced oscillations of a balanced horizontal rotor. Kinematics of a horizontal rotor. Equation of rotor dynamics considering the impact of a liquid layer. Influence of the circulating force. Determination of amplitude and phase frequency responses. Dynamic stability of a centrifugal pump's rotor.

Lect. 1; Pr. tr. 1, 2.

1. Describe the components of equations for a single-mass model of an unbalanced rotor considering external viscous friction.
2. Describe the features of the amplitude-frequency response for a single-mass model of rotor dynamics.
3. What is the magnitude of the amplitude-frequency response at the resonance frequency?
4. What is the significance of the phase-frequency response at the resonance frequency?
5. What is an imbalance?
6. Describe the factors affecting the rotor's dynamic response during the transition through resonance.
7. Describe the rotor's translational, relative and absolute rotational motion.
8. What is asynchronous precession of the rotor?
9. How many types of it?
10. Compare the types of asynchronous precessions.

11. Does synchronous precession of the horizontal rotor occur? Give reasons for your answer.

Lect. 2; Pr. tr. 3, 4

1. Describe the components of equations for the double-stiffness rotor’s motion in a noninertial origin.
2. How are critical frequencies of the 1st kind determined?
3. In what frequency range does the rotor lose its dynamic stability?
4. Describe the components of equations for the forced oscillations of an unbalanced horizontal rotor.
5. How is the critical frequency of the 2nd kind determined?
6. What is the relationship between critical frequencies of the 1st and 2nd kind?
7. Describe the kinematics of a horizontal rotor. What is the trajectory of relative motion?
8. What kind of precession corresponds to the movement of the horizontal balanced rotor? Justify the answer.
9. Describe the components of equations for a single-mass model of the pump’s rotor dynamics considering the circulating force.
10. Describe the effect of circulating force on rotor precession.
11. How is the coefficient of circulating force determined?
12. Describe (on the complex plane) each component of the equation for a single-mass model of the pump rotor’s dynamics.
13. How does the amplitude of rotor oscillations at the resonant frequency differ considering circulating force and without it?
14. Describe the algorithm of the Routh–Hurwitz method to determine the stability of a single-mass rotor’s motion.
15. How is the limiting frequency at which the rotor loses its dynamic stability determined?
16. Suggest ways to expand the frequency range at which the movement of the pump’s rotor is stable.

Topic 2. Study of rotor dynamics by discrete models of oscillations

The primary dependencies. Self-oscillation of a rotor without contact interaction with the stator. Self-oscillating precession of a rotor under contact with the stator. A mathematical model of self-oscillations for a floating ring considering dry friction. Stability and self-oscillations of a single-mass model considering anisotropy of elastic forces. Influence of internal viscous friction on dynamics of a horizontal rotor. Basic approaches to creating discrete models of rotor dynamics. The traditional discrete multi-mass model. Ways to consider the gyroscopic moment of inertia in rotor dynamics. Influence of the gyroscopic moment of inertia on rotor’s critical frequencies. Shape functions of a 2D beam-type finite element. Lagrange equations of the 2nd kind for transverse oscillations of a beam element. Matrix equation of rotor dynamics. Free and forced oscillations of the rotor’s finite element model.

Lect. 3; Pr. tr. 5, 6.

1. Describe the negative effect of self-oscillations on the vibration state of the rotor.
2. How do the equations of motion for the pump’s rotor differ in studying its self-oscillations compared to the traditional equations of rotor dynamics?
3. What self-oscillating modes of the rotor exist? What is the difference between them?
4. At what value of the rotor speed does the loss of dynamic stability, and the transition to the self-oscillating mode occur?
5. Describe the algorithm for determining the amplitude of self-oscillations of the rotor without contact with the stator.
6. What kind of precession occurs during the rotor’s self-oscillation? Justify the answer.

7. In which frequency range is the self-oscillating mode of the rotor in contact with the stator stable?
8. Describe (on the complex plane) each component of the equation for a single-mass model of the pump rotor's dynamics under contact with the stator.
9. Describe the algorithm for determining the amplitude of the rotor's self-oscillations under contact with the stator.
10. Describe the components of the motion equation for the floating ring.
11. How does dry friction affect the frequency of self-oscillating precession?
12. Describe the algorithm for determining the stability limit of a floating ring under the anisotropy of elastic forces.
13. How does the anisotropy of elastic forces affect the stability of the floating ring?
14. What is the trajectory of the floating ring's precession?
15. How are the floating ring's precession kinematic characteristics determined?
16. Write a formula to determine the precession frequency of a floating ring.
17. Find out how the anisotropy of elastic forces affects the frequency of self-oscillating precession.
18. How is the internal viscous friction force set (in the complex plane)?
19. Write the motion equation for the horizontal rotor considering the external and internal viscous friction.
20. Describe the effect of internal viscous friction on the static deflection of the horizontal rotor.
21. Does the internal viscous friction affect the dynamic deflection of the rotor? Give reasons for your answer.

Lect. 4; Pr. tr. 7.

1. What do the eigenfrequency and critical frequency of the rotor mean?
2. What are the different approaches used for creating discrete mathematical models of rotor system oscillations?
3. From what condition is the frequency equation determined to evaluate the critical frequencies of the rotor? What components does it contain?
4. What is the gyroscopic moment of a bushing part?
5. Write down and explain the formula for determining the gyroscopic moment of the disk.
6. What ways to consider the gyroscopic moment in rotor dynamics?
7. Compare the critical frequency of the cantilever rotor considering the gyroscopic moment of the disk and without it. Give reasons for your answer.
8. Describe the effect of the gyroscopic moment on the difference between the critical frequencies of the rotor and the eigenfrequencies of its transverse oscillations.

Lect. 5; Pr. tr. 8, 9.

1. What is the main idea of applying the finite element method to study rotor dynamics?
2. How are the shape functions of a beam finite element determined?
3. Write the Lagrange equation of the 2nd kind for the transverse oscillations of a beam. Describe each component of this equation.
4. How are quadratic forms determined for the potential energy of deformation, kinetic energy, and energy of dissipation?
5. Describe the local matrices of inertia and stiffness for the 2D beam finite element.

6. How are global stiffness matrices of a finite element built?
7. Describe the general approach for applying the finite element analysis to determine rotor oscillations’ eigenfrequencies.
8. Describe the general approach for applying finite element analysis to study forced oscillations of a rotor.
9. Write down and describe the expressions for determining the column-vectors of amplitudes and phases of rotor oscillations under the system of imbalances.

Topic 3. Fundamentals of balancing rotors for centrifugal machines

Conditions of rotor’s dynamic equilibrium. Types of unbalances. Equivalent systems of imbalances. The concept of a rigid rotor. Quality criteria in rotor balancing. Static balancing of a rotor. Dynamic balancing of a rotor. The phenomenon of unbalance for a rotor balanced in two correction planes at low frequency. The decomposition of a synchronous precession for an unbalanced rotor by mode shapes of free oscillations. Rotor balancing by mode shapes. The Den Hartog’s approach in rotor balancing.

Lect. 6; Pr. tr. 10, 11.

1. Formulate the dynamic equilibrium conditions for a solid body rotating at the stationary rotation.
2. How many types of rotor imbalance are there? Give the corresponding classification.
3. What is the static imbalance? Give a description.
4. Define and make a description of the moment imbalance.
5. What are the types of dynamic imbalance?
6. What the simplest imbalance system can be equal to an imbalanced system for a rigid rotor?
7. How are the modules and angles of corrective loads installation determined?
8. For which range of the length/diameter ratio of the rotor, to use static balancing is appropriate?
9. What parameters determine the accuracy of static balancing?
10. Specify a range of permissible residual specific imbalance after static balancing.
11. Describe the sequence of the static balancing procedure.
12. How is the corrective mass evaluated at static balancing?
13. Describe the method of three starts. For how many correction

planes is it used?
14. Write down the formula for the trial imbalance mass. From what condition is it determined?
15. At what angle from the zero mark is it advisable to set the trial imbalance?
16. How are the complex compliance coefficients determined in the method of three starts?

Lect. 7; Pr. tr. 12, 13.

1. Justify the unbalance phenomenon for the rotor, balanced in two planes at low speeds.
2. Describe the general approach for decomposing the deflections of the synchronous precession for an unbalanced rotor according to its mode shapes.
3. Prove that the deflection mode at the critical frequency is flat regardless of the imbalances distribution law.
4. What determines the inclination angle of the mode shape plane at the critical frequency?
5. Justify that at the critical frequency, the deflection is determined by the imbalance component corresponding to its mode shape in the decomposition of this imbalance.
6. Describe the rotor balancing algorithm by two mode shapes in three correction planes.
7. How is the complex coefficient between the system of trial imbalances and the required imbalances determined?
8. How are the magnitudes and phases of balancing loads determined when balancing according to the mode shapes?
9. Describe the Den Hartog’s approach in rotor balancing.
10. How are complex compliance coefficients determined within the Den Hartog’s approach?
11. What condition must be met by the number of correction planes, measuring points, and operating speeds when balancing by the Dan Hartog’s approach?

Topic 4. Parameter identification of mathematical models of rotor dynamics

Simple algebraic models. A generalized algebraic model. Non-algebraic models. A single experiment. A series of experiments. An implicit model. Linear parameter identification. Linear regression formula. Balancing by the calculation model of rotor dynamics. Practical balancing of a flexible rotor on the operating frequency. Application of the linear regression formula for balancing a flexible rotor by the Den Hartog's approach. Application of the linear regression formula for balancing a flexible rotor by mode shapes.

Lect. 8; Pr. tr. 14, 15, 16.

1. Describe the general approach to create a mathematical model. What groups are parameters divided into?
2. How is a simple algebraic mathematical model described?
3. What is the algebraic mathematical model in the general case?
4. Describe the realization scheme of nonalgebraic mathematical model in the general case.
5. What is parameter identification?
6. Describe the least square method?
7. Write down the error functions of the least square method for different kinds of algebraic mathematical models.
7. How are the unknown parameters of the mathematical model estimated by the least square method?
8. What is linear parameter identification? How can the coefficients of influence be determined?
9. In which case is linear identification reduced to the inverse matrix method?
10. Write down the linear regression formula.
11. Describe the general approach for balancing a flexible rotor as the linear identification of imbalances.

Modular control tasks

Questions to complete the 1st modular control are presented in pp. 4–9 (Lect. 1–5; Pr. tr. 1–9).

Questions to complete the 2nd modular control are presented in pp. 10–14 (Lect. 6–8; Pr. tr. 10–16).

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Навчальне видання

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Динаміка роторних машин
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Методичні вказівки
(Англійською мовою)

Відповідальний за випуск А. В. Загорулько
Комп'ютерне верстання І. В. Павленко

Підписано до друку . .2022. Формат 60×84/16.
Папір офсетний.
Ум. друк. арк.: , . Обл. вид. арк.: , .
Наклад: прим.
Вид. № . Замовл. № .

Видавець і виготовлювач
Сумський державний університет,
вул. Римського-Корсакова, 2, м. Суми, 40007, Україна.
Свідоцтво суб'єкта видавничої справи ДК № 3062 від 17.12.2007.