MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

Central Ukrainian National Technical University

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THEORY OF MECHANISMS AND MACHINES. INTRODUCTION

Methodical instructions for lectures

Kropivnitskiy - 2024

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Chair of Machine Parts and Applied Mechanics

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THEORY OF MECHANISMS AND MACHINES. INTRODUCTION

Methodical instructions for lectures

Recommended by the Chair of Machine Parts and Applied Mechanics for students of engineering, transport and electrical engineering specialties.
Protocol № 10, 14.05.2024

Kropivnitskiy – 2024

Methodical instructions for lectures. Theory of mechanisms and machines. Introduction / V. V. Pirogov, L. S. Olijnichenko. – Kropivnitskiy: CNTU, 2024. – 20 p.

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CONTENT

Preface

Mechanical engineering - the main branch of a modern industrially developed country - determines the level of development of the productive forces of society, is the foundation of technical progress in all branches of the national economy. In turn, the progress of mechanical engineering is determined by the perfection of the machines that are created. Therefore, deep theoretical knowledge and experience are required from the engineer, the ability not only to manage complex equipment, to use it successfully, but also to ensure its rapid progress. A modern engineer must perfectly master the methods of calculating and designing new high-speed, automated and high-performance machines.

The creation of new machines is based on the achievements of many fundamental and applied sciences, among which the theory of mechanisms and machines occupies an important place.

TMM is one of the main general engineering disciplines that provides the necessary theoretical training for mechanical engineers.

Knowledge of TMM is necessary not only for design engineers who design machines, but also for engineers engaged in their production and operation.

The basis of TMM is courses in physics, higher and applied mathematics, theoretical mechanics, engineering graphics, computing and programming.

The task of the TMM course is to prepare students for listening to courses on machine detailing, mechanical engineering technology, automated design systems, the basics of scientific research, and courses on the calculation and design of various special machines.

The study guide can be used both in the educational process and in engineering practice.

1. Introduction to the theory of mechanisms and machines. Machine and mechanism. Engineering design

1.1. Meaning and content of the course.
1.2. Basic concepts and definitions.
1.3. Mechanism and their classification. Types of mechanisms.
1.4. Machines and their classification. Automatic line and machine unit. Machine models.
1.5. Engineering design.

1.1. Meaning and content of the course

The theory of mechanisms and machines (TMM) is a science that deals with theoretical and experimental studies of the geometry of movement, dynamics and control of machine systems, individual machines and mechanisms and their constituent parts, taking into account technological issues, energy transfer, information transfer and processing. Otherwise, TMM is a science that studies the structure (structure), kinematics and dynamics of mechanisms and machines in connection with their analysis and synthesis.

The goal of TMM is the analysis and synthesis of typical mechanisms and their systems.

The tasks of TMM are the development of general methods of researching the structure, geometry, kinematics and dynamics of typical mechanisms and their systems.

Simple mechanisms that are widely used in machines, for which typical methods and algorithms of synthesis and analysis have been developed, will be called typical mechanisms.

In TMM, the choice of optimal parameters of machines and mechanisms is substantiated, methods of their rational design are determined. The more fully the kinematic and dynamic properties of individual mechanisms, performance and reliability criteria are taken into account, the more perfect the machine designs will be.

Increasing the reliability and durability of machines is primarily associated with the transition to new high-quality materials, improvement of the technology of processing parts, and the use of various means that contribute to the reduction of wear and tear. However, the main qualities of a new machine or mechanism are established precisely at the first stage of their design, when the structural (principle) scheme and the main kinematic parameters are chosen. Therefore, it is more expedient to fight with the root causes of harmful phenomena than with their consequences. It is better to eliminate large loads than to choose particularly strong materials capable of withstanding these overloads. By rational selection of the structure and

parameters of mechanisms or machines, it is possible not only to increase their reliability and durability, but also to significantly reduce overall dimensions and weight.

The TMM course can be divided into two parts: theory of mechanisms and theory of machines.

Problems of the theory of mechanisms can be divided into two groups: the first is the analysis of mechanisms, which consists in the study of their structural, kinematic and dynamic properties; the second is the synthesis of mechanisms, which consists in their design with given structural, kinematic and dynamic properties.

Problems of analysis (similarly to problems of synthesis) of mechanisms, in turn, are divided into three parts:

1) structural analysis (synthesis);

2) kinematic analysis (synthesis);

3) dynamic analysis (synthesis).

Note that the tasks of structural, kinematic and dynamic synthesis are inverted to the tasks of structural, kinematic and dynamic analysis.

Structural analysis aims to study the structure of mechanisms, their modification and classification. In kinematic analysis, the movement of bodies that make up mechanisms is studied from a geometric point of view, that is, without taking into account the forces that cause the movement of these bodies. Dynamic analysis examines the influence of forces acting on the bodies of the mechanism.

In the theory of machines, the general methods of designing schemes of machines as a set of individual mechanisms, the issue of automatic control and regulation of machines are considered.

1.2. Basic concepts and definitions

Each mechanism or machine consists of separate parts. A part is a part of the mechanism that is made without assembly operations. Stationary machines and mechanisms have fixed parts and moving parts. In moving machines and mechanisms, fixed parts are conventionally considered to be those that are permanently connected to the body. For example, in an internal combustion engine (Fig. 1.2.1, a): fixed parts - engine housing 4, crankshaft bearing 0, cylinders 5, etc.; movable - crankshaft 1, connecting rod 2, pistons 3, valves 6, etc. In fig. 1.2.1, a conventional image of this mechanism is presented.

Each moving part or group of parts that form one rigid moving system of bodies is called a moving link of a mechanism or machine.

For example, the engine connecting rod (Fig. 1.2.1, c) will be one moving link, although it may consist of a number of parts (connecting rod

body 1, bushings 2 pressed into it, liners 3 and 4, head 5, bolts 6 with nuts 7, washers and cotter pins). The parts that form one link sometimes do not have a rigid connection with each other (for example, a conveyor belt with the parts it carries); then a sign that they belong to the same link will be the absence of relative movement of parts.

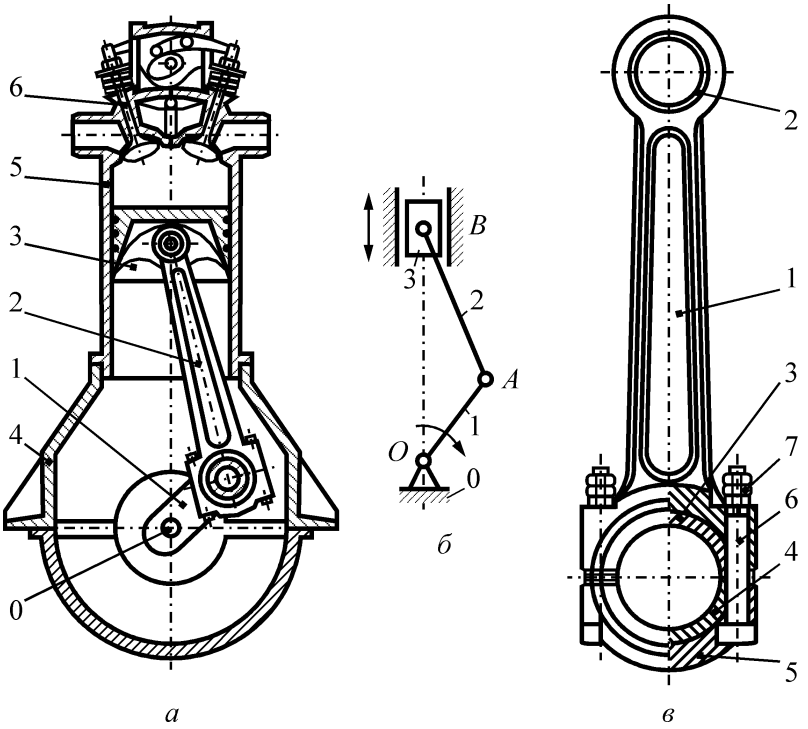

Fig. 1.2.1

All fixed parts form one fixed system of bodies, which is called a fixed link or riser. For example, the engine housing, main shaft bearings, etc. together form one fixed link, or riser.

Thus, in any mechanism or machine, we have one fixed link and one or more moving links.

In mechanisms or machines, the links are connected to each other in such a way that the possibility of their relative movement is always ensured. A moving connection of two links that collide is called a kinematic couple.

The movement of the links relative to each other is determined by the shape of the elements of the links with which they collide. The set of

surfaces, lines or points that belong to the links and that collide during the relative movement of the links are called elements of kinematic pairs.

A connected system of links included in kinematic pairs forms a kinematic chain. For example, the crankshaft of an internal combustion engine together with a stationary bearing forms one kinematic pair O (Fig. 1.2.1, b). The connecting rod with the crankshaft forms the second kinematic pair A, the connecting rod with the piston - the third (joint B), the piston with the cylinder - the fourth, and all these links and kinematic pairs together form a kinematic chain.

1.3. Machines

1.3.1. Basic concepts about machines and their types

A machine is a device that performs mechanical movement to transform energy, materials, and information in order to replace or facilitate human physical or mental labor.

The machine in its general form consists of the following main parts: the machine, the engine (converts energy), the transmission mechanism (converts movement), the executive mechanism (ensures the execution of the technological process), the control system.

Conventionally, all machines can be divided into power, work and information machines.

A machine designed to convert one type of energy into another type of energy is called an energy machine. These machines are of two types:

1. engines that convert any type of energy into mechanical energy (electric motors, steam engines, internal combustion engines);

2. generators that convert mechanical energy into energy of other types.

A working machine is a machine that uses mechanical energy to perform work on moving and transforming materials. These machines are of two types:

1. technological ones that change the properties, state, and shape of the processed material or object due to the influence of the working (executive) body of the machine on it. This is the most diverse class of machines, which includes metal cutting machines, rolling mills, metallurgical, textile, printing, agricultural machines, light and food industry machines and many others;

2. transport, which are designed to change the position of the processed material, objects or people along a given trajectory with the required speed and acceleration. Transport machines include cranes, conveyors, coaches, cars, locomotives, tractors, elevators, airplanes, etc.

An information machine is a machine designed to process and transform information. They are divided into the following:

1. mathematical, which transform input information into a mathematical model of the object under study;

2. control and control, which transform the input information (program) into control signals of the working or power machine;

3. cybernetic, which control work and energy machines and are able to change the program of their actions depending on the state of the environment (that is, machines that have elements of artificial intelligence).

1.3.2. Automatic line and machine unit

A machine in which the transformation of energy, materials and information takes place without human intervention is called an automatic machine. Automatic machines do not require human participation in the technological process, but they require the presence of so-called operators, i.e. people who monitor the operation of the automatic machine, define work programs and, if necessary, correct the operation of the mechanisms.

A set of automatic machines, connected to each other by automatic transport devices and designed to perform a certain technological process, is called an automatic line. Automatic lines are the basis of automatic shops and automatic factories. Automatic lines include energy machines in the form of an electric drive, transport machines for moving parts or conveyors, technological machines that change the shape, composition or structure of processed objects, control and control machines that control the quality and dimensions of the product and regulate the modes of movement of engines and working bodies, logical (mathematical) machines that count the number of products. Such a set of machines is called a machine assembly.

1.3.3. Machine models

A model is a device or an image of a certain object or phenomenon that adequately reflects its studied properties, and is used as a substitute for the object.

According to the form of representation, the models are physical and mathematical. By purpose: functional, structural, geometric, kinematic, dynamic. According to the research method: graphical, numerical, graphoanalytical, experimental.

1.4. Mechanisms

1.4.1. Basic concepts about mechanisms

At the heart of every mechanism or machine is a kinematic chain. Based on this, the mechanism can be given the following definition.

The mechanism is a kinematic chain with one fixed link, designed to perform well-defined appropriate movements.

Mechanisms included in modern machines are very diverse. Some of them consist only of solid bodies, others - of hydraulic, pneumatic, electric, magnetic and other devices. In this regard, a more general definition of the mechanism can be given.

A mechanism is a system of bodies designed to transform motion and forces applied to one or more bodies into the necessary motions and forces of other bodies.

It follows from the definition of a mechanism that a device in which there is no transformation of mechanical motion cannot be called a mechanism.

Each mechanism has a fixed link (a riser) and a moving link or a system of moving links. Input and output links are distinguished from moving links. The link to which movement is given, which is transformed by the mechanism into the desired movement of other links, is called the input link. The link that performs the movement for which the mechanism is designed is called the output link. The rest of the moving links of the mechanism are called connecting or intermediate.

A link for which the elementary work of external forces applied to it is positive is called a leading link. A driven link is called a link for which the elementary work of external forces applied to it is negative. The input link in some mechanisms can be both the leading and the driven.

The mechanism is called flat if all its links move parallel to one plane and the trajectories of all its points are flat curves. Otherwise, the mechanism is called spatial.

1.4.2. Classification of mechanisms

Mechanisms are classified according to the following characteristics:

1. by field of application and functional purpose (mechanisms of aircraft, machine tools, presses, internal combustion engines, industrial robots, compressors, pumps, etc.);

2. according to the type of transmission function (constant, variable, unregulated, regulated, with step regulation (gearboxes), with stepless regulation (variators));

3. by the type of motion transformation (rotary to rotary (reducers, multipliers, clutches), rotary to translational, translational to rotary, translational to translational);

4. according to the movement and location of links in space (spatial, flat);

5. on the variability of the structure (invariable (crank-and-connecting mechanism of the engine) and variable (arm of the manipulator));

6. by type of kinematic pairs (with lower, higher and hinged pairs);

7. by the method of transmission (frictional, engagement, wave, pulse-sleep);

8. according to the design and movement of links (lever, cam, gear, star, Maltese, ratchet, screw, wedge, friction, belt, chain, hydraulic, pneumatic, and electric).

1.4.3. Structural and kinematic schemes of mechanisms. Types of links

When depicting a mechanism on a drawing, a distinction is made between its structural diagram using conventional designations of links and kinematic pairs (without observing the scale) and the kinematic diagram, which is its kinematic model (with the observance of the scale).

The structural diagram contains general information about the mechanism: the number of links and kinematic pairs, the sequence, methods of connecting the links and types of possible movements (Fig. 1.4.1).

The kinematic scheme of the mechanism is built in the selected scale with the exact observance of all sizes and shapes, which depend on the movement of one or another link. The kinematic diagram should contain everything that is necessary to study the movement.

On the diagrams, links are marked with Arabic numerals 0, 1, 2, 3,..., and kinematic pairs and various points of links (for example, centers of gravity) - with Latin letters A, B, C, S2 ....

Links are distinguished by structural features (engine housing, crankshaft, connecting rod, piston, gear wheel, etc.), but most often - depending on the nature of their relative movement (Fig. 1.4.1 and 1.4.2).

Types of links:

• riser is a link relative to which the movement of all other links of the mechanism is determined (Fig. 1.4.1, link 6; Fig. 1.4.2, link 4);

• crank – a link of the mechanism that makes a full rotation around a fixed axis (Fig. 1.4.1, link 1);

• rocker arm – a link that makes an oscillating movement or a rotating link of a lever mechanism that makes an incomplete rotation around a fixed axis (Fig. 1.4.2, link 3);

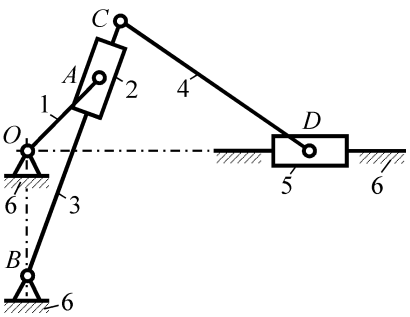

Fig. 1.4.1

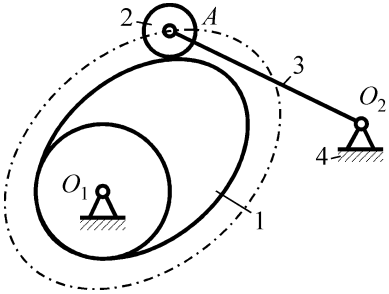

Fig. 1.4.2

• slider – a link that carries out translational rectilinear movement relative to the riser, or a link that forms a translational kinematic pair with the riser (Fig. 1.4.1, link 5);

• connecting rod – a link of the lever mechanism that carries out plane-parallel movement (Fig. 1.4.1, link 4);

• pulley – a link of the lever mechanism that rotates around a fixed axis and forms a translational pair with another moving link (Fig. 1.4.1, link 3);

• rocker stone – a link that carries out translational movement relative to the movable guide – the rocker (Fig. 1.4.1, link 2);

• cam – a link that has an element of a higher kinematic pair made in the form of a surface of variable curvature (Fig. 1.4.2, link 1);

• gear wheel – a link with a closed system of teeth, which ensures the continuous movement of another gear wheel.

1.4.4. The main types of mechanisms

1.4.4.1. Lever mechanisms

Mechanisms consisting of rigid links connected by kinematic pairs that allow only rotational or translational movement are called lever mechanisms. In fig. 1.4.3 shows the two-link lever mechanism, in fig. 1.4.4 – crank-rod mechanism, in fig. 1.4.5 – four-link rocker mechanism, in fig. 1.4.6 – four-link lever mechanism.

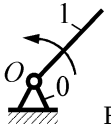

Fig. 1.4.3

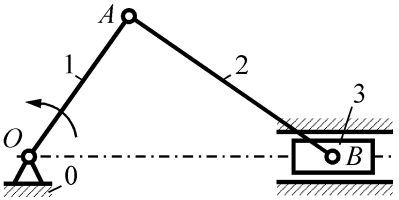

Fig. 1.4.4

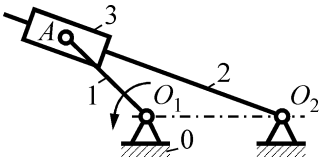

Fig. 1.4.5

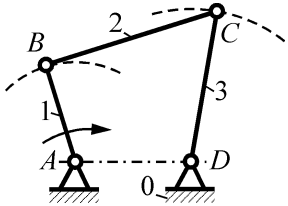

Fig. 1.4.6

1.4.4.2. Cam mechanisms

Cam mechanisms are designed to convert the rotational movement of the driving link (cam) into a predetermined law of reciprocating movement of the driven link (pusher). In fig. 1.4.7 shows a cam mechanism with a reciprocating pusher and power locking (with the help of a spring), in fig. 1.4.8 – a cam mechanism with a rotary-moving pusher and a geometric lock.

1.4.4.3. Friction transmissions (mechanisms)

In friction gears or mechanisms, the rotational movement between the links (rollers or rollers) is carried out due to the friction that occurs between them. In fig. 1.4.9 shows a friction transmission with cylindrical rollers with power locking (using a spring), in fig. 1.4.10 – frontal friction transmission with the possibility of adjusting the magnitude and direction of the angular velocity of the output link.

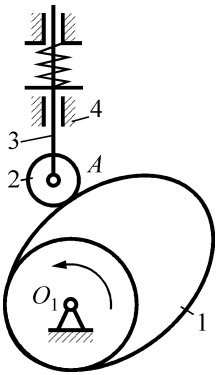

Fig. 1.4.7

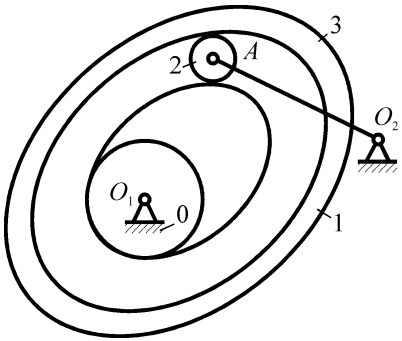

Fig. 1.4.8

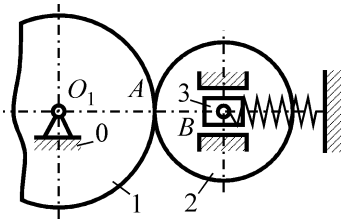

Fig. 1.4.9

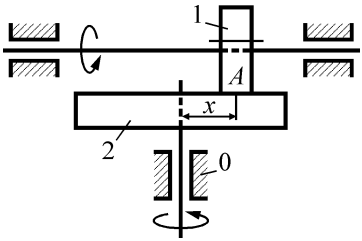

Fig. 1.4.10

1.4.4.4. Gears (mechanisms)

Gears or mechanisms are used to transmit rotary motion from one link (shaft) to another with specified angular velocities. In fig. 1.4.11 shows a gear with external engagement and parallel axes, in fig. 1.4.12 – gear transmission with internal engagement and parallel axes, in fig. 1.4.13 - bevel gear with intersecting axes, in fig. 1.4.14 - worm gear with cross axes, in fig. 1.4.15 - planetary gear mechanism, in fig. 1.4.16 – differential mechanism.

1.4.4.5. Ratchet and Maltese mechanisms

Intermittent motion mechanisms include: ratchet mechanisms, Maltese mechanisms.

Ratchet mechanisms belong to mechanisms of intermittent action, which ensure the movement of the driven link in only one direction with periodic stops. Maltese mechanisms are designed to transform the uniform rotation of the leading link into periodic movements with stops of the driven link, work smoothly without shocks (unlike ratchet mechanisms). In fig. 1.4.17 shows a non-reversible ratchet mechanism with internal engagement, in fig. 1.4.18 – reversible ratchet mechanism. In fig. 1.4.19 shows the Maltese mechanism.

1.4.4.6. Mechanisms with flexible links

In addition to the mechanisms with solid links discussed above, flexible links (belts, chains, tapes, etc.) are used. Mechanisms with flexible links (belt and chain transmission) are used with significant wheelbases, and are also used as the primary drive from the engine. In fig. 1.4.20 shows a belt drive with a tension roller.

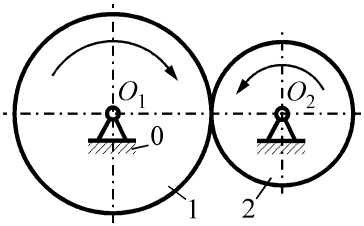

Fig. 1.4.11

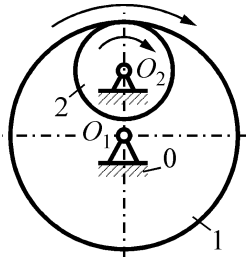

Fig. 1.4.12

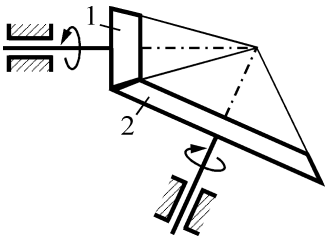

Fig. 1.4.13

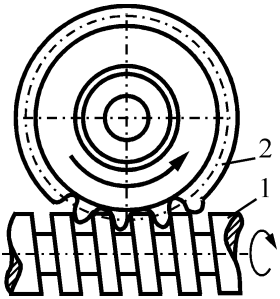

Fig. 1.4.14

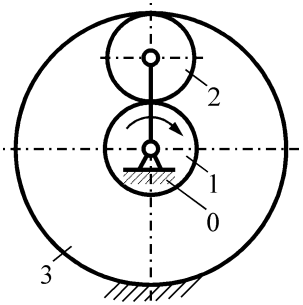

Fig. 1.4.15

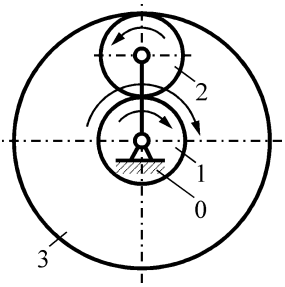

Fig. 1.4.16

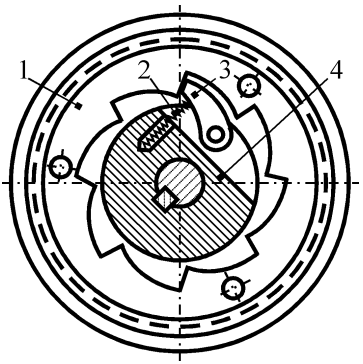

Fig. 1.4.17

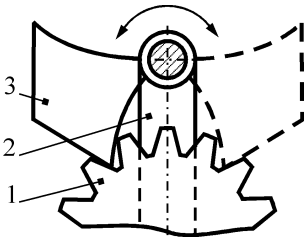

Fig. 1.4.18

1.4.4.7. Wedge and screw mechanisms

Wedge and screw mechanisms are three-link. They consist of a rack and two moving links that form three kinematic pairs. They are used for various types of presses, parts feeding mechanisms, jacks, pick-ups, etc. In fig. 1.4.21 shows a simple wedge mechanism, in fig. 1.4.22 – three-link screw mechanism.

1.5. Engineering design

1.5.1. Basic concepts

Engineering design is a process in which scientific and technical information is used to create new systems, devices or machines.

Designing is the process of drawing up a description (in different languages: graphic – drawings, diagrams, charts, graphs; mathematical – formulas and calculations; engineering – explanatory notes) necessary to create a non-existent object.

A project is a set of documents and descriptions in different languages, necessary for the creation of new systems, devices or machines.

1.5.2. Design methods

The following design methods are distinguished:

a) direct analytical methods of synthesis (developed for a number of simple typical mechanisms);

b) heuristic design methods – solving design problems at the level of inventions (for example, an algorithm for solving inventive problems);

c) synthesis by methods of analysis - a selection of options for possible solutions according to a certain algorithm with a comparative analysis of a set of qualitative and operational indicators;

d) automated design systems (CAD) – a computer program environment models the design object and determines its quality indicators.

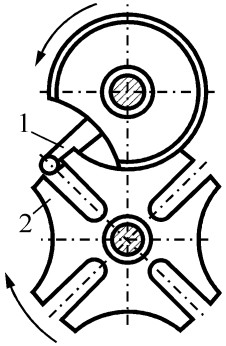

Fig. 1.4.19

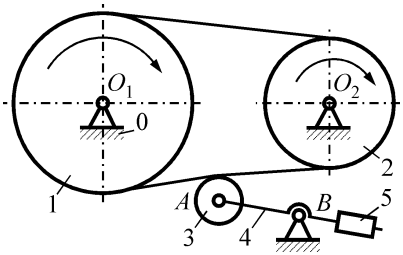

Fig. 1.4.20

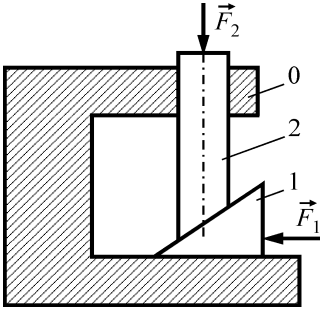

Fig. 1.4.21

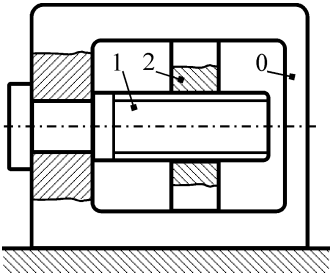

Fig. 1.4.22

1.5.3. The main stages of the design process

When designing a new technique, there is a need to carry out work related to the analysis and synthesis of a new design.

The analysis is carried out with the specified dimensions and weight of the links, when it is necessary to determine: speeds, accelerations, acting forces, stresses in the links and their deformations.

Synthesis is carried out at given speeds, accelerations, acting forces, stresses or deformations. At the same time, it is necessary to determine the necessary dimensions of the links, their shape and mass.

The main stages of creating a new design are:

1. the need to create a new structure;
2. design specifications;
3. analysis of existing technical solutions;
4. development of a functional scheme;
5. development of a structural scheme;
6. synthesis of the kinematic scheme;
7. static force calculation;
8. sketch project;
9. dynamic force calculation;
10. force calculation including friction;
11. calculation and construction of parts and kinematic pairs (calculations for strength, balancing, balancing, vibration protection);
12. technical project;
3. working project (development of working drawings of details, manufacturing and assembly technology);
14. production of experimental samples;
15. test samples;
16. technological preparation of serial production;
17. serial production of the product.

When designing complex mechanisms, they usually try to single out from the general scheme individual, simplest typical mechanisms, the design of which has its own regularities. Moreover, from the point of view of structure, kinematics and dynamics, any mechanism can be replaced by a conditional lever mechanism with its subsequent analysis, so the structure, kinematics and dynamics of lever mechanisms are considered in more detail.

1.6. Questions for self-control

1. What does the theory of mechanisms and machines study?
2. What problems are solved in the theory of mechanisms and machines?
3. What is studied during the structural, kinematic and dynamic analysis of mechanisms?
4. What are fixed and fixed parts and links?
5. What is called a kinematic pair and link?
6. What is called a mechanism and a machine?
7. What machines are there and how are they different?

8. What are energy, work and information machines intended for?

9. What machines are designed to change the shape and size of the part, energy?

10. What are mechanical transmissions for?

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Theory of mechanisms and machines. Introduction

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Compiler: V. V. Pirogov

Підп. до друку Формат 60x84 1/16 (А5). Папір друк №3. Друк офсетний.
Умов. друк. арк. Ум. фарбо-відб. Облік.-вид.арк. . Тираж прим.
Зам. №

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