TOMSK POLYTECHNIC UNIVERSITY

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MACHINE SHOPS DESIGN

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The study aid is focused on methodology of designing machining and machine-assembling shops for modern engineering factories. Special attention is given to design sequence and principles, labour intensity and workplace organization, equipment layout and arrangement in shops, auxiliary system design. The standard reference data used in engineering is cited.

The study aid is designed at Automated Engineering Technology department of Tomsk Polytechnic University. The manual is intended for training students majoring in the specialty 150700 «Mechanical engineering».

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INTRODUCTION

The main goal of the discipline is to train specialists to realize the designed manufacturing processes when implementing the new equipment, modernizing, reconstructing manufacture and creating new shops. So it is necessary to know the fundamentals of how to design workshops and services rationally.

To achieve this goal it is necessary to master modern design methods of machining and machine-assembling shops based on the newest scientific and technical researches, as well as principles of constructing automated production processes, ensuring high productivity and technical and economic efficiency. When designing a production process in machine-assembling shops, special attention should be given to interconnection of stages through which end product is made, to quantitative and qualitative changes of a work site, and also to the basic and auxiliary industrial systems.

The project basis of a division and shop is an elaborated technological part that defines the leading role of the process engineer in the course of designing machining and machine-assembling manufacture (all in all – mechanical assembly production). The solution to other sections (building, power, sanitary-engineering, etc.) is subordinated to the requirements of the master schedule (technological process) which defines the contents for working out these sections of the project.

When designing it is necessary to solve a number of questions connected with performing production processes, therefore you should have a sound understanding of economics, production organization and management, maintenance, materials and instrument supply, etc. Even small errors and ignoring insignificant factors lead to essential reduction of production efficiency and even to its stopping.

Problems of designing divisions and shops are extensive and diverse that demands broad-based knowledge in various areas of science and technology from the designer, therefore the discipline «Machine Shops Design» is studied at the last stage of preparing a process engineer and it is based on the knowledge of all previously studied disciplines.

Scientific views on production engineering of machine-assembling manufacture were first expressed in works of Russian scientists I.A. Time, P.A. Gavrilenko, M.E. Egorov.

Nowadays requirements for production quality of machine industry and its variety become stricter, there is a fast renewal of products which has essentially new character and requires applying more perfect equipment and different manufacturing organization. So, 20 years ago in leading automobile corporations a new car model appeared every 2–4 years, now the renewal occurs ones in several months. Under the conditions of acute competitive struggle less time is devoted to development of new products but product range becomes wider. That results in assembling several sample pieces (even the customized ones) on one assembly-line. Consequently, it is necessary to foresee equipment replacement and forthcoming re-planning to improve design techniques and create new high–performance plants.

1. BASIC DEFINITIONS

The machine-assembling manufacture consisting of a number of manufacturing areas and auxiliary departments is a complex dynamic system whose structure and parametres depend on the construction complexity, product range and specifications of manufacturing process. Moreover, it is often necessary to produce new articles meeting up-to-date requirements.

Production of essentially new articles can be realized in three ways:

1. *Modernization* – the new equipment is placed in an old building without changing the construction elements of the building.
2. *Reconstruction* of old buildings for the new equipment. In this case the old equipment can also be used but placed in another way, according to the manufacture organization being designed.
3. *Construction of new buildings* with new equipment. In this case the old equipment is rarely used because of moral and physical ageing.

Reconstruction, in comparison with construction of a new building, allows starting the production faster, requires less expenditure, pays its way 3 – 5 times faster. However, if the building is too old, new equipment is king-sized or requires a completely different location, it is preferable to construct a new building.

In all cases the building should meet the requirements of manufacturing process.

A production process in machine building is a set of operations necessary for manufacturing end products from semi-finished articles and materials. The technological process (the master schedule) of articles manufacture underlies in production process. To ensure delay-free implementation of production process in machine-assembling manufacture auxiliary processes are set in motion.

The basic stages of production are:

1. getting and storing materials, blanks (performs), semi-finished articles;
2. cutting off materials (rods, sheets, bars and so forth) for blanks;
3. delivering blanks, semi-finished articles or materials to working position (machine tools, benches);
4. various kinds of blanks (workpieces) processing (handling): moulding, forging, press forming, machining with chip (swaft) removal (turning, milling, drilling, grinding, broaching, etc.) and without chip removal (burnishing, calibration, etc.); thermal, painting, etc.;
5. transporting blanks between working positions;
6. quality inspection at specially assigned places (sample or absolute);
7. storing blanks in storehouses between processes;

8. storing workpieces (sometimes called articles) after their complete processing;

9. assembling products from the parts machined at the own plant, received in cooperation or bought;

10. trialing and regulating;
11. painting and furnishing;
12. packaging;
13. storing in a storehouse before shipping;
14. sending to the consumer (customer).

Various stages of production can be executed:

- In various specialized shops and engineering departments (forge-stamping shop, turning shop for shafts, milling, etc.). Such production is called *differentiated*;
- In one shop or department. Such production is called *complex*.

Productions are divided on flow-line and non-line production.

Flow-line production (process) is a production (process) at which a blank or an assembled article while being manufactured is in movement (fixed or periodic), and this movement is carried out within a fixed *timing period* at a considered time interval. For example, the blank after the 1st process gets immediately to the 2nd and so on up to the last one. The duration of any process is equal or multiple (if duration of any process big) to a timing period.

Non-line production (process) – the duration of production (process) is various and the blanks between processes lie at special places.

Flow-line production is usually organized in mass and large-scale manufacture and it requires very careful calculation, otherwise there are failures and production efficiency significantly decreases.

The output programme is fixed for each manufacture – it is a set of blanks or articles of a particular range which are produced in the given volume per year. The quantity of blanks or articles which are to be manufactured for a particular period of time (a year, quarter, month) is called *a production volume*.

Each manufacture has a certain *capacity* which is the ability to produce maximum quantity of product(s) of a particular range in a certain time frame at the defined work mode (amount of working days in a year, amount of shifts in a day (in the working day), operating time of the equipment during one shift). There is actual capacity and design capacity. *Design capacity* is the capacity which can be reached on condition that the manufacture is provided with production facilities, personnel, production organization accepted in the project. The actual capacity is not constant and depends on many factors of the existing manufacture.

Manufacturing articles takes certain time. The calendar time during which the article remains in the production process, from the beginning of manufacturing through the output of a finished product, is called *a production cycle*. There is a settlement cycle and an actual cycle. When the processes are nonperiodically repetitive, it is better to use the term *in-process time*, instead of *cycle*.

The movement of blanks, semi-finished components or articles in manufacture can be carried out per piece or in batches. A *batch* is a certain quantity of blanks, semi-finished components or articles which are delivered simultaneously to a working position (place).

To carry out a production process working positions (places) should be arranged in an appropriate way. Depending on the process content and its organization the technological equipment, semi-finished blank storage, a worker or a group of workers, equipment for automatic loading and unloading (robots, manipulators, automatic loading machines), cutting and control measuring tools, attachments (fitting-out), maintenance and labour protection facilities, control elements can be located at a working position (place). An example of a working position is shown in Fig. 1.1.

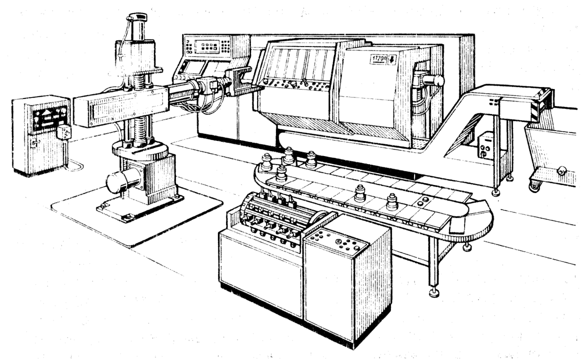


Fig. 1.1. A working position

Due to organizational reasons, some working positions are integrated, forming a manufacturing area achieving its primary purpose. *A production floor* is a part of a workshop where the work places (positions) are located. They are integrated with part handling-and-storage devices, maintenance, tool and metrological service facilities, management and labour protection facilities. Here technological processes of manufacturing articles for a particular purpose or some processes are carried out.

A workshop is a larger organizational unit which represents an industrial administrative separate division of a factory (plant). The shop includes manufacturing areas, auxiliary departments, offices and welfare spaces, places for public organizations. Auxiliary departments are created for serving production floors and ensuring that they work without interruption. These departments include the cutting tool restoration department, the control and maintenance department, the department for preparing and distributing cutting fluids, etc. The composition of production floors and auxiliary departments is defined by the construction of fabricated articles, technological process, production programme and facility management.

Usually the shop occupies a separate place. But when plants are large or shops are small (there are less than 100 people working) and equipment is small-sized, several shops are located at the same place. Equipment arrangement is connected with a technological process therefore a technological process is the base for division or shop design.

Depending on functional areas equipment is divided into two groups: basic (technological) and auxiliary. Basic equipment is used for executing operations of a technological process directly. Auxiliary equipment is the equipment which is not directly used in a technological process of manufacturing articles, but it serves the basic production.

The total area of a shop *in technological calculations* is the sum of industrial and auxiliary areas.

The industrial area is the area occupied by working positions (places), auxiliary equipment which is placed at production floors, aisles and passages between equipment within production floors (except the area of the main aisle way).

The *auxiliary area* is the area occupied by all the equipment and devices of the auxiliary systems, which have not been located in manufacturing area, as well as the main aisle ways and fire brigade access.

For driving mobile loaders, cargo vehicles and sweepers there are main aisle ways in shops which are not less than 4.0 meters wide. This width corresponds to the technological design standards.

Offices and welfare spaces are located in the utility area of the shop. The *office* area is occupied by the administrative services of the shop. The area also contains the area of design and production engineering offices. *Welfare spaces* are the area intended for hygiene and sanitary needs as well as for social needs of the personnel working in the shop.

Certain staff is provided for performing production processes and it is divided into the following categories: production (basic) and auxiliary workers, engineering and technical personnel, office employees, junior service personnel.

Production workers are the workers of machine-assembling manufacture who directly perform operations of manufacturing process.

Auxiliary workers of machine-assembling manufacture are the workers who do not take direct part in production. They serve the manufacturing processes.

Engineering and technical personnel are officers responsible for production management, production organization and manufacturing preparation. They hold the positions which require the engineer or technician qualification.

Office *employees* are the personnel responsible for performing administrative functions, such as financing, accounting, solving social and similar questions in accordance with the position held.

Junior service personnel are watchmen, cloakroom attendants and cleaners of offices and welfare spaces.

One of the machine shop design stages is workshop arrangement. *Workshop arrangement* is relative positioning of manufacturing areas, auxiliary divisions, main aisle ways, offices and welfare spaces in the shop area. After workshop arrangement the equipment layout is carried out. A *shop layout* is relative positioning of technological and auxiliary equipment as well as other manufacturing facilities and devices in the shop areas.

One of the production organization parameters is *goods traffic* which represents the sum of homogeneous cargoes (in tons, pieces) displaced in a certain direction between separate loading and unloading points in a particular time frame (hour, shift, day and etc.). Goods traffics differ in the form of cargo, direction of travel and goods traffic intensity. *Goods traffic intensity* is understood as a number of transports moving through a considered site per time unit.

Machine-assembling manufacture is usually located in the buildings having one or several spans. *Span* is a part of a building limited in longitudinal direction by two parallel rows of columns. The distances between columns axis in longitudinal direction is called *column space*, and the distances between columns axis in a cross-section direction – *width of span*. The distances between column axis in cross-section and longitudinal directions form a *column grid*. A *span height* is a distance from the floor level to the lower parts of a bearing structure of the roof construction.

When designing an up-to-date machine-assembling manufacture it is necessary to orient to full automation. The automation level of the main and auxiliary processes, defined by technical and economic reasons, should be the same, if possible, since the capacity of the whole automated complex will be defined mostly by the "weakest" link in a production chain.

2. PROJECT DESCRIPTION

In general, the design problem can be formulated as following: to design a shop or a production floor responsible for manufacturing products of a particular range at a defined quality; the output programme should be fulfilled with reduced expenditures for production as low as possible, and with taking into account all the requirements of labour safety.

When designing a machine-assembling manufacture technological, economic and organizational problems, which are closely interconnected, are worked out and solved simultaneously.

The *technical design* is a set of the process flow documentation containing technological and economic calculations, an explanatory note, drawings, schemes and other materials necessary for constructing a building and organizing manufacture. The design is usually divided into main and special sections.

The *main section* includes technological and transport parts and contains the definitions and calculations of all production elements to organize a manufacturing process.

The main section should contain working drawings of parts; working drawings of blanks with the calculated and indicated stocks (the stock is a thickness of metal layer removing to eliminate the defects from the previous processing), providing the least material waste, and tolerances for blank sizes; a justification of a base choice at machining; route and process checklists in accordance with the fixed form; calculations and a choice of cutting modes in accordance with standards or specification; time evaluation of machining or its assessment in accordance with the specification; operational sketches of machining; calculations relating to defining part positioning accuracy in attachments; drawings and sketches of attachments with corresponding calculations.

The calculations of a quantity of basic and auxiliary cutting and measuring tools, technological equipment are made on the base of developed manufacturing processes for producing articles.

As a result, lists of equipment, attachments, cutting and measuring tools, basic and auxiliary materials, production and auxiliary staff, junior service personnel, office staff, *engineering and technical personnel* are made.

The main section should contain the developed auxiliary systems: warehouse, transport, tool management, repair and maintenance service, product quality inspection, consumer service and labour safety, production preparation and management.

Special sections are:

1. Architectural and building.
2. Sanitary-engineering (running water, heating, ventilation, sewerage, lighting, etc.).
3. Electrotechnical (electrical supply, communications, fire and burglar alarms).
4. Heat and power (air, gas).
5. A development plan and local transport.
6. Labour organization and manufacture management system.

Each part has the following materials:

- The explanatory note containing a brief description of the manufacture elements (the master schedules, the applied equipment, a layout of locations, the feasibility report on accepted decisions);
- Applications to the explanatory note (required calculations, tables, technical data of machine tools, specifications and etc.);
- Drawings, schemes, experimental models.

3. DESIGN SEQUENCE

Creating modern effective manufactures requires large material expenses, long design and implementation periods, considerable efforts of cross-function specialists, participation in work of many organizations and enterprises (main design organization with skilled architects, subdesigners, experts of the corporate customer (the technologists, personnel of the capital building department of the enterprise), developers and manufacturers of the equipment and engineering tools, installation and building organizations). Front end engineering design has a special value when creating machine-assembling manufacture. It is carried out for the purpose of gathering raw data, analyzing the existing production level, working out the *feasibility report* of the project or technical and economic calculation of expediency to create a new production, to extend, reconstruct or modernize the existing manufacture, working out a technical project request and preparing various technical materials to carry out design works.

Front end engineering design often has two stages:

1. initial investigation and working out the feasibility report (FR) or technical and economic calculation (TEC);
2. working out and accepting a technical request to create and implement a manufacturing system (design specification).

Estimating organizational-technological structures of the enterprise is the base when choosing objects for creating an effective manufacturing system. It is defined by the specialization of the basic industrial divisions – shops and production floors, to be exact, by conformity assessment of their specialization, character and type of production.

When reconstructing manufacture it is necessary to have a greater amount of raw data, than when designing a new manufacture since there are the existing buildings, constructions, equipment, etc. used. Therefore before reconstructing a group of designers go to the factory where they study the manufacture, select and systemize the necessary data about the factory and its departments. For complex inspection of the factory the group consists of technologists, a power engineer (for estimating energetic conditions), a builder engineer, an economist and other experts.

If the reconstruction deals with a radical change of the manufacture profile to produce absolutely new products which were not fabricated earlier, the inspection concerns primarily the data about the premises and factory shops, as well as about the available equipment but it does not examine the questions of labour and machining contents of former articles, labour productivity and other data which do not relate to the manufacture of new articles.

The main inspection objective is to study industrial, material, financial and manpower resources of the operating manufacture. The inspection is carried out thoroughly by several parts before reconstructing the manufacture.

1. The common and technical-and-economic parts include the common data about operating machine-assembling manufacture, the data about its composition, production volume and production range, production cooperation, production facilities, the data about working staff and their qualification, salary level, production cost, common outputs and basic technical and economic indexes.

2. A development plan, transport and storage facilities.

3. The technological part contains data about the purpose of the shop, product yield and production cooperation (internal and external), shop location, working mode, labour and machining contents of manufacturing, manufacture organization, shop facilities and manufacturing processes.

4. The building part contains data about natural and engineering-geological conditions of the area, building description, conditions of building realization.

5. The sanitary-engineering part and industrial water supply contain data about the existing sources of water supply, systems and constructions of sanitary sewers, industrial sewage, intrashop sanitary-engineering installations.

6. The power engineering part contains the data about the power and heat supply, heat and steam sources, air and gas supply, intrashop industrial pipe system, energotechnological data of test stations, stands, data about power resources cooperation.

On the basis of the inspection results the feasibility report on the expediency of creating a new manufacturing system of the project is developed. The feasibility report should contain a short estimation of the existing industrial system condition, its readiness for transformation and prospective scales of implementation taking the specification of the inspected factory and production yield into account.

The key parameters of the manufacturing system (machining and labour contents, quantity of working staff, structure and quantity of the equipment, demand for space and etc.) are defined in the feasibility report in the minimum time frame and are subject to updating at the follow-up stages of working out a piloting project and the technological part of the development project. In the feasibility report, along with investment costs, technical and economic indexes which are to be reached should be specified including the decrease of machining and labour contents, the increase of work load factor and equipment shift-working, the decrease of labour force and production area, the decrease of production lead time and etc.

The technical decisions accepted in the feasibility report should correspond to the perspective directions of developing and introducing new equipment. They should be based on applying advanced achievements in the field of progressive resource saving technology, highly automated equipment, computer equipment and its software. The created manufacturing system due to its technical and economic indexes when implementing should correspond to the best domestic and foreign samples.

If the factory is supposed to introduce several automated sites, it is reasonable to plan their introduction in one industrial division (shop) in order to have a possibility to automate all auxiliary processes in the department. In the case when it is necessary to change the organization structure for creating new manufacturing system, partial or complete reorganization of the manufacture should precede the project development. Complete reconstruction and manufacture modernization are more preferable, however, their implementation in a short time frame is real only in conditions when they are stipulated by the corresponding plans and provided with the necessary resources. Otherwise, it is necessary to limit to the partial reorganization aimed at creating separate domain-specialized manufactures.

Inspection data also include the annual reported data of the enterprise preceding the year of working out the development project and the planning data at the moment of inputting and developing the design capacity. The data of each part of the feasibility report is checked and specified in the inspected area by the chief engineer and the chief designer of the project.

Approved by the heads of general design organization and the customer, the feasibility report is the base for working out a piloting project and technical request for creating a manufacturing system.

The decision by the administration board or the ministry directive (for the factory which is a part of the ministry) is the base to start pre-design operations for creating a new manufacturing system.

Designing production floor and shops, reconstructing or extending them, as well as modernization are carried out in accordance with design assignment which includes all raw data got during the pre-design period.

Design assignment is carried out by the customer of the project together with the design organization taking into account the data of the feasibility report.

When developing design assignment it is necessary to solve the following problems: technical, economic, organizational, and social.

Technical problems:

a) To work out technological processes for each part (article);
b) To calculate labour coefficient of manufacturing all parts (articles) per year;
c) To determine the equipment type for each operation of all technological processes (for all parts or articles);
d) To calculate the required amounts of all manufacture elements (machine tools, personnel, the areas and etc.);
e) To execute building arrangement, shopfloor and equipment layout;
f) To work out the problems relating to labour and environment safety.

To solve these technological problems it is necessary to examine the questions of article technological effectiveness, to design technological processes for each part (article), to determine labour and machining contents of processes, to determine a type and quantity of the equipment, amount of staff, material consumption rate, to define the areas and the sizes of production floors and shop, to develop shopfloor arrangement and equipment layout, to define task for building, sanitary and power design.

Economic problems:

a) To justify economic feasibility of accepted technical decisions;
b) To calculate cost price and profitability;
c) To calculate the amount of permanent and current assets;
d) To solve the problems of financing at the period of designing, building and developing production yield, and the questions of credit reimbursement;
e) To solve the problems of supplying the factory with raw stuff and materials, from several sources (duplication for emergencies).

Organizational problems:

a) To work out the principles of organizing industrial divisions (shops);
b) To work out the management structure;
c) To solve the problems of labour management, supply of working positions with blanks, tools and materials;
d) To organize manufacture services (storehouse, transport, quality inspection and etc.).

Social problems:

a) To create convenient labour and rest conditions;

b) To organize catering services, supply of the goods and products;
c) To organize health services.

When the efficiency of the design decision is estimated by several indexes of various dimensions, the multi-criteria estimation of decision quality can be used; thus the selected indexes are estimated according to the significance which is defined on the base of the statistical data. When designing several variants of the machine-assembling manufacture project or its parts it is necessary to select the optimal one.

There are two periods of designing: pre-design and project time frame.

The *pre-design period* is preparatory. It includes:

1. Clarifying the task set. Gathering the required data: drawings or sketches of parts, production schedule of each part in the near future and in the long term; verifying ready-made manufacturing processes or developing the missing ones (it is detailed for mass, large-scale and medium-size production, and it is less detailed for small-scale and single-piece production); calculating labour input for machining and assembling; calculating the amount of equipment for the mainline and auxiliary productions; calculating working and total areas.
2. Project feasibility study on expediency to create a new production, to extend, reconstruct or modernize the existing manufacture.
3. Choosing the areas for constructing.
4. Developing technical design specifications taking into account all information updated. The technical design specifications should get the consent of all competent authorities (sanitary, fire protection, water canal, telephone, traffic police, ecological, state supervision and etc.) and after that it is approved by the town-planning council in the town hall.
5. After approving a planning permission is received and the areas for target building are reserved. The permission is received for a certain period of time (usually 1-3 years) during which it is necessary to present the finished project.

The technical design specification includes:

1. The variety and product yield (in kind and in value terms).
2. An estimated workshop arrangement and layout.
3. A choice justification of the area, its size, a relief, geological survey data, conditions of area development.
4. The variety and volume of the blank fabricated and received from other factories.

5. A working mode and effective lifetime of the equipment (a number of shifts and shift duration, how many hours per year the equipment should work with consideration for repair and maintenance).
6. Effective work time of workers.
7. The requirements of environment protection and waste recycling.
8. When and at the expense of whom it is stipulated to extend manufacture, its sizes.
9. The order of introducing objects into service

Designing can be carried out in two stages and in one stage. O*ne-stage* design is carried out when there is a standard project (the project was made for someone some time ago, it was approved by all the authorities and it is available in the archive). It is the cheapest and fastest method of designing.

Two-stage design is carried out in accordance with the unique project. In this case the *project* is first carried out according to the technical *design specification*, it gets the consent of all competent authorities (as well as the technical specifications), it is approved by the town-planning council in the town hall and after that the planning permission is received (usually for a period of 1-3 years). In addition, the building organization and inspection stages of constructing (a foundation pit, the foundation and etc.) are usually stated. After the project having been approved by the town-planning council the second stage takes place – preparing *the engineering documentation* for the project (the calculation of the required amounts of floor slab panels, bricks, concrete and etc.).

Such sequence of design is applied to decrease expenditures. So, for example, detecting inadmissible decisions at a technical specification stage will enable you to avoid unnecessary expenditures for designing which makes up about 10 % of building expenditures that accounts for millions of roubles.

The design is usually carried on by some design organization which has license for the given kind of work. A leading design organization can charge some aspects of work to subcontractors (ventilation system design, power supply and etc.). At the design stage one should orient to a particular building organization, take into account work specification and material application. It is extremely important to select the design and building organizations thoroughly since it influences on the quality of work and the amount of problems which may occur when defending the technical specification and project in the town-planning council as well as introducing objects into service.

4. COMPUTER-AIDED DESIGN (CAD) SYSTEMS OF DIVISIONS AND SHOPS

Increasing requirements for developed project quality and reducing execution periods of design works result in constant design process improvement. The base of a CAD system is a manufacturing process of computer-aided design which is represented in the form of a continuous repetitive activity of executing design processes.

The main function of CAD system is to make effective decisions when developing design objects. Efficiency level of executing design procedures is estimated through the technical-and-economic indexes whose analysis determines influencing factors on a manufacturing process design. Thus, feedback which enables to improve the system *continuously* is created coordinating the interactions between its component parts in order to reach the demanded effect.

When developing or selecting a CAD system it is necessary to orient to systems which realize open and continuous decision-making processes by working out design objects, sorting out the processes of gathering and processing information, and to reduce interaction between developers by means of decision unification, typification of mutual requirements between project parts, and also to allow selecting optimal variants from a designed set [2].

The continuity of decision-making process is provided by mutual requirement standardization of the project sections, creation of specifications, unified decision base and centralized storage of reference information.

The fundamentals of CAD industrial systems consist of four hierarchical levels and two subsystems — designing and ensuring. The first subsystem, being a subject-oriented part of a CAD system, solves design problems, and the second – represents general-system methods and means ensuring execution of the design process. At the first level of hierarchy of a CAD system there is a definitive forming of the project and results of the second level decisions are used. At the second level the basic and auxiliary systems are designed. At the third and fourth levels of hierarchy each subsystem is represented as a set of programs and subprograms.

When designing divisions and shops the following problems are solved by a CAD system:

1. Calculating total labour and machining contents according to types of equipment for the given production programme.
2. Calculating the amount of equipment, basic and auxiliary workers.
3. Calculating the industrial and auxiliary areas.
4. Choosing optimum shopfloor arrangement and equipment layout.

5. Calculating transport and storehouse facilities, cutting and auxiliary tools, control and measuring equipment, etc.
6. Calculating project technical-and-economic indexes.

It is possible to solve the specified problems by creating the unified technological modules and system approach to designing homogeneous manufactures. Developing and applying the unified modules in the basic and auxiliary systems allows to arrange design decisions and to improve a technique of designing machine shops.

The basic difference between a CAD system and a traditional design system is that computer design becomes, first of all, an organizational-technical system in which operations of designers and operations of engineering tools have a permanent connection and are integrated by a common aim. Achieving the goals in this system is ensured with the accepted methodology and engineering tools, planning and management processes.

Another distinctive feature of a CAD system is informational flow integration as a system-organizing factor at all stages of the project development. Design decisions are taken on the basis of conducting mathematical experiment with a simulation model of a designed shop or its component elements.

Automation assumes the transfer of such functions as direct engineering management, the coordination of the formed decision with the shop efficiency indexes to the computer. Ensuring the intercomputer coordination is possible only if a computer memory has a complex of designed shop models and a computer archive of the *normative* references (databank).

The system approach to solving unification problem requires decomposition of design objects in order to select unification objects with homogeneous physical and formal characteristics, as well as to take into account their interconnections for unitizing the chosen elements. Object decomposition shows the sequence of its functions at decision-making levels.

When decomposing objects functionality and minimality principles are used. The functionality principle is that the elements chosen at decomposition should be isolated whenever possible, i.e. it is possible for them to formulate their own purpose of any level element functioning which should be reached by a set of functioning purposes of the subsequent level elements of which it consists.

The minimality principle consists in deriving minimum decomposition levels that reduces the amount of measurement units of unification problems. Degree of unification should be restricted to such level on which the unification problem can be solved without expanding the internal element content.

As machine-assembling manufacture design is a multipurpose and repetitive process, there is a close correlation between various aspects of its provision. The structure of providing system is shown in Fig. 4.1 [2].

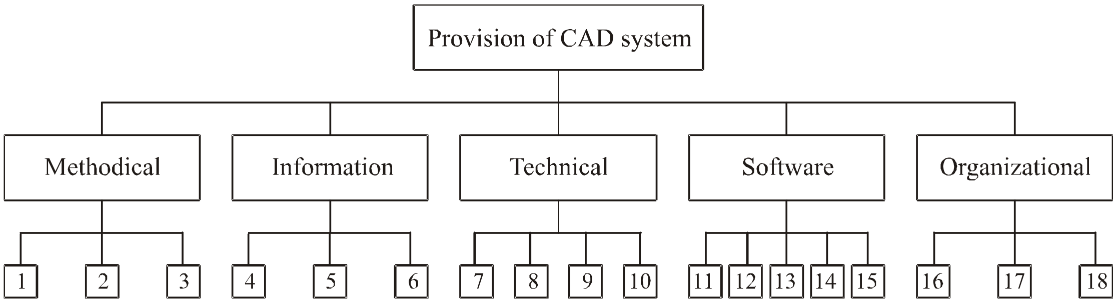


Fig. 4.1. Provision of CAD system: 1 – computer-aided design theory; 2 – unification principles, estimated figures and regulations; 3 – mathematical methods, models, algorithms and object description languages; 4 – information content of databanks; 5 – data flow structure and diagram; 6 – documentation formats; 7 – computing facilities; 8 – terminal equipment; 9 – transmission facilities; 10 – means of information storage; 11 – operating systems; 12 – programming systems; 13 – database management, specialized management programs; 14 – dialogue and computer graphics control; 15 – program modules, engineering computations modules and other programs; 16 – computer-aided design management; 17 – improvement of design organization structure; 18 – computer-aided design technology

Direct connection consists in the fact that the task for developing, for example, equipment support, is made in the course of creating information support of higher level, and the feedback between various types of support lies in the fact that requirements of one support to another should be imposed taking into account the possibility of their satisfaction.

Information support receives its realization in a databank, and maintenance is realized by the software developed to satisfy optimum operating modes.

Technical, informational and programme bases are the contents, and economic-organizational support is the fundamentals of the system and should reflect methodological principles of its creation.

Developing organizational structures of design divisions refers to organizational aspects due to their specialization, interaction of control and realization elements, creation of continuous technology of computer-aided design. The block diagram of computer-aided design system is presented in Fig. 4.2.

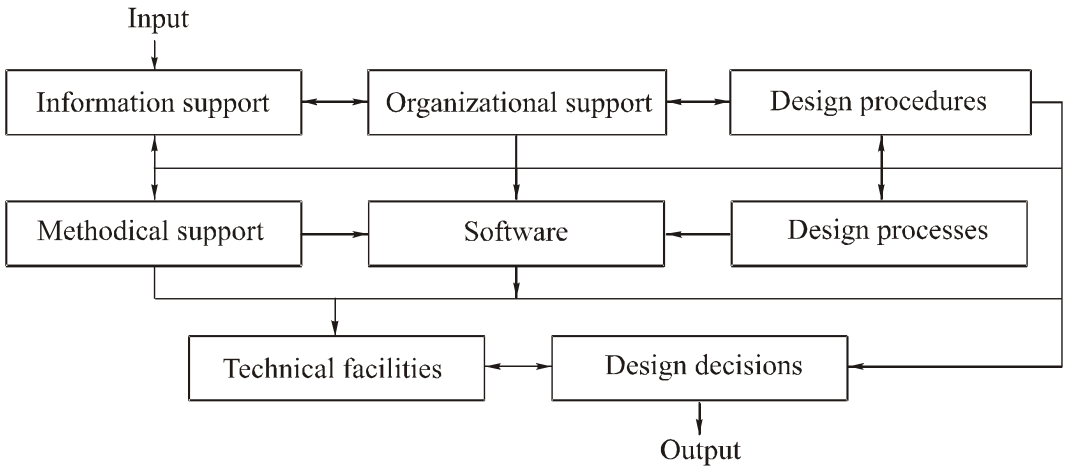


Fig. 4.2. The CAD system block diagram

A set of requirements for creating a providing system, first of all, refers to data input and output, to organizing interaction between the human and computing machinery, to forming databases, to processing information and to communications.

The integration principle is widely used for all aspects of support. This principle has allowed justifying and formulating informational integration in the form of databases, programme integration – in the form of applications packages, technical integration – as a full complex of technical facilities, organizational integration – as a set of organizational and economic principles assumed as basis of building computer-aided system and interaction unity of its components.

Modern requirements for design are characterized by two basic directions:

1. developing methods and means for increasing efficiency and decisions quality, i.e. the decisions ensuring the highest specific production yield per unit of capital investments;
2. creating techniques to increase labour productivity of designers.

Creating advanced design decisions demands that decision-making techniques should be by improved by using mathematical simulation and computing facilities, rational use of human resources at the expense of more accurate regulation of employees' activity. It results in changing the labour organization that allows using knowledge and experience of designers more rationally. Such process organization should be created on the basis of the systems analysis methods, scientifically well-founded forecasting, with due regard for conditions and factors influencing on projects quality, increase of accuracy and reliability of input data, unification of design decisions, introduction of estimated figures and design regulations.

Another important condition of ensuring projects efficiency is development of trial design methods in case of incomplete information, choosing and estimating cost-effective decisions at the basic design stages. At traditional design the estimation of decisions quality, as a rule, is executed at the final stage of development, and the majority of decisions is defined approximately. Creating a project normative base ensures an estimation of intermediate decisions and organization of continuous design processes.

The project quality is characterized by a set of project properties stipulating its ability to perform according to intended functions which are built into when designing and revealed when implementing and operating. The project quality degree represents the relative performance based on the comparison of technical-and-economic indexes of quality and corresponding sets of standard indexes.

The factors influencing on project quality are technological discipline and labour quality of employees, development line balance, completeness and objectivity of standard-methodical base, technological support of design process, methods and means of projects development and corresponding labour management of designers.

The quality assurance system provides decisions estimation at initial and intermediate design stages and it is realized by using mathematical models and computers with consideration for alternative study of basic decisions.

In the structure of quality assurance system the important role belongs to the selection of design stages where control functions of employees' labour and design decisions are performed.

To develop quality assurance means it is necessary to improve organizational structure of design divisions by broadening specialization of labour and creating divisions necessary for performing new functions. Thus, special divisions should be created to develop standard-methodical support and new design modes: department of computer-aided design with a computation centre and computer workstations, quality sector, design decisions unification sector, laboratory for analyzing rated capacity, authorial supervision sector, scientific labour organization sector, sector of automated control system of design organization, sector for examination of compliance with regulatory documents.

The effective decision of the problems which designers face is impossible without creating the unified decision base and modelling on their basis design objects, developing methodical fundamentals of effective project design. The intended methodical fundamentals should reflect a current status of normative and technological support, estimation of efficiency of traditional design methods and tools, justification of interconnection quantity between project sections and quality of tasks given, detection and analysis of deficiencies in the engineering specifications, an estimation of organizational means and efficiency of operational administration of design processes, assessment of conditions influencing on quality degree of projects. Studying the influence of each of these factors gives a chance to formulate practical recommendations how to improve a design process. For this purpose the technique of data gathering is created. It contains the analysis of structure and functions of designed manufacture, basic indexes of project development organization, means and methods for design quality assurance.

Designing machine shops is a multipurpose system. The resulting function of a design system is characterized by its efficiency depending on its subsystem functions which, as well as the system, are described by the structure, its components, interconnections, parameters and functional properties.

One of CAD system design stages is to define an architecture and role of separate subsystems when functioning. Moreover, the close interconnection of project sections complicates design modelling and algorithmization. The greatest difficulties arise at optimization of the project quality as a whole. A problem decision received by stage-by-stage optimization due to separate parameters of quality can differ considerably from the optimum problem decision as a whole.

5. DESIGN PRINCIPLES

When designing it is necessary to adhere to the following principles:

1. Flow-lining of production.
2. Production automation.
3. Specialization and cooperation.
4. Unification and standardization.
5. Flexibility of production.
6. Industrial aesthetics.
7. Production standards.

1. Flow-lining of production. The most effective from the economic point of view is mass production. To define the type of manufacture the *coefficient of assigning operations* is used

$$K_{\text{f.o.}} = n / C, \tag{5.1}$$

where: n – is a quantity of the operations performed at a site, a machine tool line or in shop within one month; C – is a quantity of working positions (machine tools) in a site, line or shop which are used for performing n operations.

In accordance with Russian state standard specification (GOST) 3.1108-74 the following classification of manufacture types includes:

1. Single-piece production: $K_{\text{f.o.}} > 40$.
2. Small-size production: $40 > K_{\text{f.o.}} > 20$.
3. Medium-size production: $20 > K_{\text{f.o.}} > 10$.
4. Large-scale production: $10 > K_{\text{f.o.}} > 1$.
5. Mass production: $K_{\text{f.o.}} < 1$.

The type of manufacture from the technological point of view is characterized by an average number of operations performed at one working position, and it defines the degree of specialization and features of the equipment used. The distinction degree of processes content is also important. If the configuration of the parts machined on one machine tool does not differ considerably, it takes not much time and effort to readjust the equipment. It is necessary to take the features of the equipment into account: readjustment of a special unit machine is more difficult than a turning multiple-purpose machine. Within one shop there can be different types of production at different divisions.

The highest form of organizing mass production is flow-line production. *Advantages*: 1) it disciplines manufacture at the expense of a timing period; 2) it is easier to automate; 3) incomplete production decreases. *Disadvantages*: it requires developing a manufacturing process thoroughly.

2. Production automation is applied after careful technical and economic study. Automation allows reducing the amount of workers, but the amount of maintenance personnel (service technicians, designers, programmers, etc.) increases. Automation for mass production (automatic transfer lines, unit-type machine tools, automatic machines and semiautomatic machines, etc. with "fixed" programming by means of cams are usually used, but NC (Numerically Controlled) machine tools can also be used) differs from a small-scale manufacture where NC machine tools are used.

The main drawback of using NC machine tools is the high cost of the equipment (sometimes 10 times higher than usual), big complexity of control systems that demands more staff to serve the equipment. Applying the NC equipment is justified when there are not less than two shifts and sufficient quantity of single-type machine tools at a site (not less than 3 units for multi-machine tool work).

The basic criterion for choosing equipment configuration of the shop is minimum reduced expenditures E for annual output:

$$E = C + R_n \times I, \qquad (5.2)$$

where C is the cost price of annual output; R_n = 0.15 – normative effectiveness ratio of capital investments; I – the capital investments meant for annual production volume including the cost of equipment, tools, buildings; expenditures for incomplete production, housing and public amenities buildings.

Production automation development as well as modern trends in machine building industry characterized by the increase of relative density of high-variety serial production and the reduction of product life cycle in mass production resulted in creation and widespread adoption of *flexible manufacturing systems (FMS)*.

According to GOST 26228–85 flexible manufacturing systems is a set of various combinations of NC equipment, *robotized technological complexes (RTC)*, *flexible manufacturing modules (FMM)*, separate units of processing equipment and support systems of their functioning in an automatic mode during the target time interval. This FMS possesses a property of automatic readjustment when producing a wide range of articles within the fixed amount of values of their characteristics.

According to organizational criteria there are the following flexible manufacturing systems: *flexible transfer line (FTL)*; *flexible manufacturing cell (site) (FMC)*; *flexible automated workshop (FAW)*; *flexible manufacturing automated factory (FMAF)*.

A flexible manufacturing module consists of a processing equipment unit and it is equipped with automated programmed-controlled means and automation equipment for engineering procedures (loading, unloading devices). It can function autonomously or it can be built in a system of a higher rank.

FTL and FMC consist of several flexible manufacturing modules, integrated by the automated control system. In flexible transfer lines the equipment is located in sequence of executing technical operations, and flexible manufacturing cells have a possibility to change the sequence of the equipment used.

A flexible automated workshop represents a set of FTL and FMC in various combinations intended for manufacturing articles of the given range, for example: a machining shop, assembling shop, heat treatment shop, etc.

A flexible manufacturing automated factory represents a set of FAWs intended for output of the finished articles.

The industrial structure of flexible manufacturing systems includes two basic complexes: a manufacturing complex and *supervisory computer control system (SCCS)*. When constructing complexes and their components the system approach is used: each component is considered as a system consisting of engineering tools for automation and mechanization of physical labour and administrative functions with a certain order of their interaction.

In turn, the manufacturing complex includes a manufacturing system and a production supporting system (PSS). FMS supporting system is a set of interconnected systems providing manufacturing preparation of articles, control of flexible manufacturing systems by means of the computer, storage and automatic transportation of production facilities and technological equipment).

In general, a production supporting system consists of:

1. an automated transport or transport-storehousing system (ATS);
2. an automated tool management system (ATMS);
3. a computer-aided inspection system (CAIS);
4. an automated waste disposal system (AWDS);
5. an equipment maintenance and repair management system (EMRMS);
6. an automatic process control system (APCS);
7. a computer-aided design system (CAD system);
8. a generative planning system (GPS);
9. an automated control system (ACS of FMS), etc.

According to two forms of specialization of machining sites (cells) – technological and subject – there are two possible directions to create a flexible manufacturing system.

The first direction involves automation of separate manufacturing operations and creating operational flexible manufacturing systems (turning, milling, grinding).

The second direction is characterized by complete integrated automation of engineering procedures of processing parts of a certain class that in conditions of fast readjustment ensures much greater efficiency in comparison with the efficiency of operational flexible manufacturing systems. Organizational fundamentals of a flexible manufacturing system are the group technology ensuring minimum equipment downtimes because of readjustment at part specialization of divisions and shop. In this case technologically homogeneous operations of processing *various parts* of one or several different articles are performed in a division.

For this purpose all parts (or articles) are classified beforehand according to constructive-technological criteria (similar in structure and machining technology). Then these parts are integrated into groups according to the applied equipment, adjustments and tooling equipment. After that group engineering procedures are developed, they allow machining any parts of the group in a division by using common manufacturing procedures.

Group methods in the conditions of flexible manufacturing systems ensure sharp reduction of in-process time and interoperational transfer processes, reduction of incomplete production and essential speedup of mastering new parts (articles).

According to group technology principles you can create a flexible manufacturing system for manufacturing turned parts (shafts, flanges, sleeves, gear wheels, etc.); case-shaped parts and spatial swing arms and bars, plane parts (bars, covers, flat bars, panels, etc.); mixed groups of parts consisting of the parts which belong to the groups enumerated above.

You can take full advantages of flexible manufacturing systems if a complete manufacture of parts is carried out in the automated line segment. However, due to the absence of flexible manufacturing systems for some manufacturing operations, and the necessity to use the available equipment in the shop, it is possible in well-founded cases to perform separate processes in other divisions with lower level of automation.

In this case a flexible manufacturing system is used as a component of a division or a shop having lower level of automation.

Nowadays there are three types of decisions of flexible manufacturing systems applied in machining. They are:

1. Creating flexible sites and lines from available at a factory and series-produced NC machine tools. Moreover, sites are supplemented with automated transfer systems, store rooms; machine tools are equipped with automated loading devices. Such flexible manufacturing system

is used by factories which have a wide experience of running NC machine tools and well developed computer centres;

2. Creating lines and sites on the base of standard decisions which are developed by machine building research institutes and design engineering departments and series produced FMS;
3. Creating a flexible manufacturing system on the base of special development using new advanced decisions and equipment designed according to the modular principle (multi-station work centres, flexible transfer lines with multiple-spindle machining heads, etc.).

The first type of the decision is suitable for improving and reconstructing the manufacture, the second and the third types of decisions are connected with essential renewal of the manufacture.

One should mention high cost of flexible manufacturing systems. Therefore, when choosing the equipment it is necessary to define the rational degree of manufacturing system automation. The common approach to apply automated systems is illustrated with the diagram shown in Fig. 5.1.

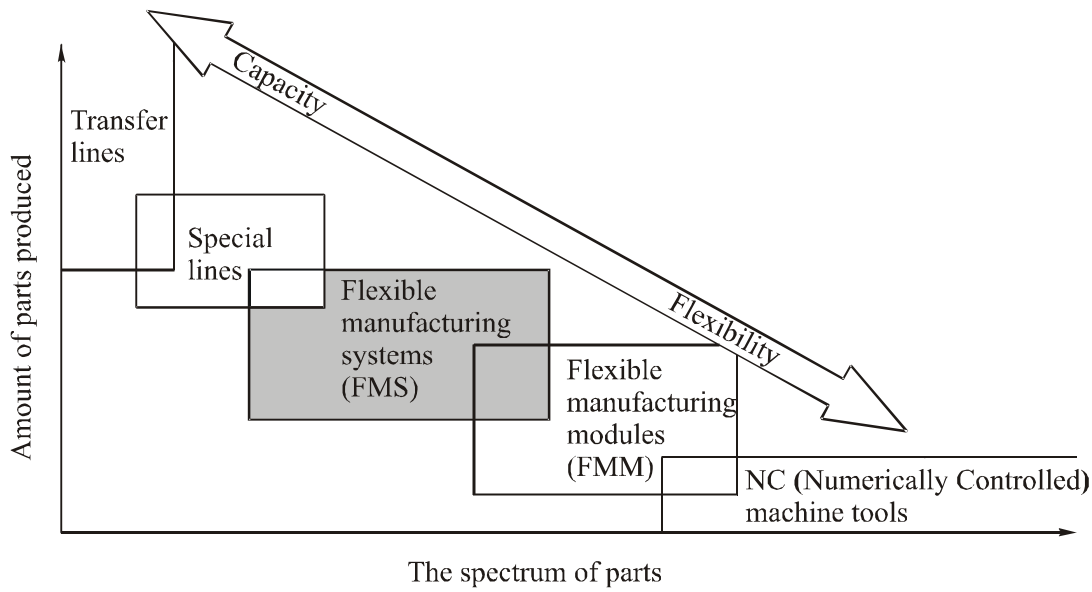


Fig. 5.1 Efficiency of the automated manufacturing systems with flexible technology

Flexible manufacturing systems are intermediate between rather low efficient NC machine tools possessing high flexibility and mass production transfer lines which are high-efficient but far less flexible. Special lines represent complexes of a large scale production with multi-station unit-type NC machine tools equipped with transfer systems.

The basic sources for increasing FMS efficiency are increasing the share of machine time at the expense of reducing auxiliary time at automatic blank changing and reducing changeover time, increasing operation rate up to 2.5–3.0, reducing investments in circulating assets by decreasing start batches and production cycle.

Therefore, when choosing an FMS composition and degree of transfer system automation, tool management system and quality inspection it is necessary to estimate admissible expansion of value for a manufacturing system in comparison with the cost of the system when using stand-alone NC machine tools.

3. Specialization and cooperation are an integral part of increasing production efficiency. *Specialization* is a form of labour division in general. It is caused by concentration of production and capacity expansion that allows applying purpose-designed and special machine tools with high capacity. Specialization allows applying more productive techniques (for example, one can use pull broaching instead of shaping) that decreases the production *cost price*.

There are three boundaries of specialization:

1. Economic (when there is the least cost price of production).
2. Physiological (when specializing at working position worker's fatigue rises because of work monotony).
3. Social (poverty of work content-richness). To reduce negative effect of this factor it is recommended to change a working position periodically.

Specialization can be:

1. workpiece (only certain parts are processed in a division);
2. article (only certain article is assembled or produced);
3. technological (a foundry shop, forge shop, shop for roughing machine operations and etc.).

At specialization parts are produced in big quantity. So it is necessary to sell them to somebody. In this case *cooperation* is required. Cooperation is work of a group of factories to output some products. For example, one factory manufactures shafts on the automatic transfer line, another – gear wheels, the third – casts and processes mechanism bodies.

4. Unification and standardization are necessary actions at specialization and cooperation. *Unification* is a reduction to uniformity of output product forms. For example, electrical sockets produced by one factory should fit to electrical plugs produced by another factory. *Standardization* is an introduction of uniform standards and requirements, for example, introduction of particular measured parametres when producing gear wheels.

5. Flexibility of production means ability to readjustment. It is a very important factor in the violent competitive struggle. Rearrangement can be carried out without changing the equipment (if the old equipment allows mastering a production of new articles) and with changing. When it is necessary to change the equipment, rearrangement can be carried out at a full stop of manufacture and in parallel with mastering new production in special areas. The second way is more preferable. Therefore, when designing a shop it is necessary to reserve some place for installing new equipment. Usually this place is not empty – there is an additional line located, or it is used as an area for interoperation storage and etc. When rearranging the production output will be carried out only on one line.

It is necessary to take *constructive-technological* and *construction-mounting* measures in order to increase manufacture flexibility.

As for the *first group of measures* it is necessary to apply such designer decisions that there are no problems with searching and purchasing new equipment. When designing manufacturing processes it is desirable to apply more general-purpose equipment or equipment with a big range of workpiece sizes. In case of group technology the precision technology for a complex part (not existing in reality, but containing all aspects of real part machining) is developed, and each particular part is processed according to this adjustment with corresponding correction, and some transitions are not executed at all. Using this technology it is necessary to group parts correctly and to provide equipment groups for them.

The list of *construction-mounting* measures contains:

1. Use of quick-change foam panels instead of capital wall partitions. Using capital wall partitions is acceptable only if there are special requirements for locations (for example, for providing fire safety of store rooms with combustibles and lubricants).
2. Application of a large column grid (in the future columns should not prevent from equipment reinstallation). A column grid is the distance between columns in cross-wise (L) and lengthwise (t) directions. The following column grids ($L \times t$) are applied: 12×6; 12×9; 12×12; 18×6; 18×9; 18×12; 24×6; 24×9; 24×12 m. Applying unreasonably large grid demands to use longer floor slab panels and increase building cost. It is preferable to use not reinforced-concrete columns, but metal ones (usually I-beams) to make erection easier.
3. Equipment installation on vibration-damping springs (vibration insulation) that allows moving the equipment quickly. Installation on

the individual foundation is applied only to the machine tools with reciprocation (grinding, planing machine tools, etc.), as well as to heavy or precision equipment.

6. Industrial aesthetics is of great importance for increasing labour productivity. It contains:

1. Creating rational and convenient working places, their arrangement.
2. Arranging consumer services.
3. Comfortable and smart clothes of workers.
4. Rational workplace illumination.
5. Solving problems of house-keeping.

7. Production standards are understood as degree of sophistication of interdependent questions. The high production standards allow increasing the quality of production and keeping it stably at a high level.

6. RAW DATA FOR SHOP DESIGN

To design a shop the following main raw data is required:

1. A production programme for each part (the name and the annual production programme).
2. A working drawing for each part.
3. Operation requirements for fabricated articles.
4. A master schedule for each part.

If it is intended to undertake a reconstruction, the inspection data of an existing shop or factory is required in addition:

1. The existing master schedules.
2. The available equipment and its condition.
3. Tool shop facilities (the equipment, workers' qualification, work load during the forthcoming period) to produce shop auxiliaries for the designed workshop.
4. A layout of the existing workshop. The special attention is given to arrangement, availability of the independent ground work, a column grid, floor-to-ceiling height and availability of bridge and other cranes, access roads.

The production programme can be: 1) accurate; 2) reduced; 3) conditional.

1. *Design under the accurate programme* is carried out in the conditions of mass and large-scale productions. The detailed technological process for each part or an article is thus made with floor-to-floor time and floor-to-floor time is calculated for each technological operation.

2. *Design under the reduced programme* is carried out in the conditions of small-scale and medium-sized productions. All articles are conditionally reduced to several typified articles which are more specific for different groups. The following sequence is thus observed:

- All drawings are divided into groups according to their constructive-technological similarity. Usually they are groups of shafts, sleeves, disks, case-shaped parts, gear wheels and etc. The similarity of manufacturing process and used machine tool types and attachments lies at the heart of division into groups.
- From each group the *part-representative* is selected or the *complex part* which has all types of machining of the given group is created. The *part-representative* has the highest accuracy and the greatest quantity of machining aspects. At this stage it is important not to

miss some aspect of machining (for example, broaching or key slotting), demanding the specific equipment.

- For the part-representative (or the complex part) a manufacturing process is made in detail, a machine tool model, floor-to-floor time and total floor-to-floor operations are defined for each process.
- The operations made in the designed shop are defined, and labour input of machining the part-representative (or the complex part) in the designed shop is calculated.
- For other parts in the group labour input is determined through *the reduction coefficient* calculated for each part,

$$T_i = T_{\text{repr.}} \times K_{\text{red}_i}, \qquad (6.1)$$

where T_i – labour input of machining the considered part in the designed shop; $T_{\text{repr.}}$ –labour input of machining the part-representative (the complex part) in the designed shop; $K_{\text{red}.i}$ – *the reduction coefficient* of the considered *i* part.

The reduction coefficient is determined in accordance with the formula

$$K_{\text{red}_i} = K_{\text{w}_i} \times K_{\text{s}_i} \times K_{\text{c}_i} \times K_{\text{m}_i}, \qquad (6.2)$$

where: $K_{\text{w}\,i}$ – the reduction coefficient of weight (it would be more correct to use the reduction coefficient of the processed area of the part, but it correlates with the weight of the part which is written in the part drawing); $K_{\text{s}\,i}$ – the reduction coefficient of seriality (the more the production programme, the more possibility of applying special attachments which reduce time for part installation); $K_{\text{c}.i}$ – the reduction coefficient of complexity; $K_{\text{m}.i}$ – the coefficient considering the influence of the process material type on the cutting mode.

There can be a lot of such coefficients (for example, coefficients considering a blank surface condition, application of cutting fluids and etc.), but the first three factors are usually applied. They are determined as follows:

$$K_{\text{w}_i} = \sqrt[3]{\frac{W_i^2}{W_{\text{rep}}^{\;2}}}, \qquad (6.3)$$

where: W_i – weight of the considered *i* part; W_{rep} – weight of the part-representative.

The *reduction coefficient of seriality* is determined depending on the ratio of the annual production programme of the part-representative to the annual production programme of the considered *i* part (N_{rep}/N_i):

$$K_{\text{s}\,\text{i}} = (N_{\text{rep}} / N_i)^{\alpha}, \qquad (6.4)$$

where: α – power exponent; α=0,15 for factories of light and medium machine building; α=0,2 for factories of heavy machine building. It is possible to apply the following coefficients for medium machine building:

if $N_{rep}/N_i \leq 0.5$, the $K_s = 0.97$;
if $N_{rep}/N_i = 1.0$, the $K_s = 1.0$;
if $N_{rep}/N_i = 2.0$, the $K_s = 1.12$;
if $N_{rep}/N_i = 4.0$, the $K_s = 1.22$;
if $N_{rep}/N_i = 8.0$, the $K_s = 1.28$;
if $N_{rep}/N_i = 2.0$, the $K_s = 1.12$;
if $N_{rep}/N_i \geq 10$, the $K_s = 1.37$.

The *reduction coefficient of complexity* (K_S) allows for the influence of workability of industrial product on machining content of processing or labour intensity of assembling. In general, it is possible to represent the reduction coefficient of complexity (K_S) in the form of a coefficient product considering the dependence of labour intensity of the considered article and features of its design. For homogeneous parts of the group the most essential parametres are accuracy and surface roughness of the part:

$$K_c = \frac{K_{a\_i} \times K_{r\_i}}{K_{a\_rep} \times K_{r\_rep}}. \quad (6.5)$$

Accuracy and roughness factors of the *i* part (K_{a_i}, K_{r_i}) and the representative part (K_{a_rep}, K_{r_rep}) are determined by Table 6.1 and 6.2. Average accuracy (average accuracy degree) is defined as the sum of accuracy degree numbers of all sizes of the part divided by the quantity of the considered sizes. The average roughness is defined in the same way.

Table 6.1. Accuracy factors (K_{a_i}, K_{a_rep})

Average grade of tolerance	6	7	8	11	12	13
K_{a_i} or K_{a_rep}	1.3	1.2	1.1	1.0	0.9	0.8

Table 6.2. Roughness factors (K_{r_i}, K_{r_rep})

Average roughness, *Ra*, a micron	20	10	5	2,5	1,25	0,63
K_{r_i} or K_{r_rep}	0.95	0.97	1.0	1.1	1.2	1.4

- After determining the reduction coefficient for each part labour intensity of the annual programme is calculated for each part in the group: $T_{Ni} = T_i \times N_i$. Labour intensity of machining the annual programme of all parts in the group is calculated as the sum of labour intensity of the annual programme for each part: $T_{\sum Ni} = \sum T_{Ni}$.

- Labour intensity for other groups of parts is calculated in the same way as mentioned above.
- Total labour intensity of all parts machined in the designed shop is calculated in this way: $T_{gen.} = \sum T_{\sum Ni}$.

If each group of parts is machined only at a separate site in the shop, the further calculation of the amount of machine tools at each site is carried out according to labour intensity of the annual programme of all parts only in this group $T_{\sum Ni}$. If the parts of all groups are machined at sites irrespective of a certain group, the further calculation of the amount of machine tools is carried out according to the total labour intensity of all parts $T_{gen..}$

3. *Design under the conditional programme* is carried out according to rapid calculation. All parts are divided into groups of constructive-technological similarity, in each group the part-representative is selected, a detailed technical process is made for them, and labour intensity of other parts in the group is considered to be the same ($K_{red\ i}$=1).

For rapid (in less detail) calculation there can be a *design by technical-economical indexes (TEI)*. Calculation according to *by technical-economical indexes* can be done in value terms (production output per a year in roubles per one machine tool, per one worker, per one square metre of a floor space and etc.), in weight terms (production output in kilograms per 1m^2 of floor space, per one machine tool and etc.), in physical terms (items per 1m^2 of floor space, per one machine tool and etc.).

7. WORKING MODE AND WORKING TIME ARRANGEMENTS

The working mode is the amount of working days a year, amount of shifts a day, shift length in hours. There are the following time arrangements:

1. *Calendar* – F_{cal}=365 days×24 hour = 8760 hours.
2. *Nominal* (*operational*) – how long the equipment can work in the set working mode without repairing:

$$F_{\text{n}\,m}=[365 - (52+8)]\times 7\times m-56\times 1\times m, \qquad (7.1)$$

where 365 – a number of days in a year; 52 – a number of days-off in a year; 8 – a number of public holidays; 7 – shift length (in hours); m – a number of shift a day; 56 – a number of days before days-off with the labour shift reduced by 1 hour.

At single-shift work (m=1) $F_{n\,1}$ = 2070 hours, at double-shift working F_{n2} = 4140 hours, at three-shift working $F_{n\,3}$ = 6210 hours.

3. *Actual* (*effective*, or *estimated*) – how long the equipment should work in the set working mode subject to scheduled preventive maintenance and visual inspections (emergency maintenance is not included in the calculation)

$$F_{\text{r}\,m} = F_{\text{n}\,m} \times(1-p/100\ \%) = F_{\text{n}\,m}\times \text{K}, \qquad (7.2)$$

where p – loss of time for scheduled preventive maintenance and visual inspections, %; K – the factor considering losses of time for scheduled preventive maintenance and visual inspections.

Losses of time for scheduled preventive maintenance and visual inspections depend on shift amount a day (the more the amount of shifts, the more difficult it is to organize repairs without stopping the equipment), complexity of the equipment and its weight. For machine tools up to 11th degree of repair complexity (for example, the lathe 1K62) there are the following norms:

At m=1 p=2 %, K=0.98, $F_{\text{r}\,1}$ = 2030 hrs.;
At m=2 p=3 %, K=0.97, $F_{\text{r}\,2}$ = 4015 hrs.;
At m=3 p=4 %, K=0.96, $F_{\text{r}\,3}$ = 5960 hrs.

For other types of the equipment (machine tool or MT) the actual annual time arrangement (in less detail) is shown in Table 7.1.

Table 7.1

The actual annual time arrangement of the equipment

Equipment type	Working mode, hrs.		
	1 shift	2 shifts	3 shifts
Machine tools to 10 tons	2040	4060	6060
Machine tools from 10 tons to 100 tons	2000	3985	5945
NC machine tools to 10 tons	----	3890	5775
NC machine tools from 10 tons to 100 tons	----	3810	5650
Unit-type machine tools	----	4015	5990
Assembling workplace with power-actuated devices	2050	4080	6085
Assembling workplace without power-actuated devices	2070	4140	6210

The actual annual time arrangement of the worker depends on the length of working week, the length of basic leave and time losses for sick leaves (on the average per one person). It is considered that the worker should work only in one shift, therefore there is no F_{r} in marking the amount of shifts.

Table 7.2

Actual annual time arrangement of the worker, $F_{r\,w}$

Duration		Actual annual time arrangement of the worker, (in hrs)
Working week (in hrs)	Basic leave (in days)	
41	15	1860
41	18	1840
41	24	1820
36	24	1610
36	36	1520

8. CALCULATION OF BATCH SIZE AND CYCLE TIME

In conditions of serial and a small-scale production the annual programme of an article manufacture is not performed all at once, but it is divided into batches. The *batch of workpieces* is a number of parts which are put into production simultaneously. It is caused by the fact that the customer usually does not need the whole annual programme at once but regular arrival of the ordered items.

Another factor is reducing incomplete production: if it is necessary to assemble, for example, 1000 reducers, then manufacturing 1000 shafts №1 will not allow to assemble any reducer until there will be at least one kit.

The batch size influences on:

1. The *output capacity of the process* and its *cost price* at the expense of a time share for preparatory works ($T_{p.f.}$) per one article in operation

$$t_{c.\,f.\,i} = t_{p\,i} + T_{p\text{-}f\,i} / n, \qquad (8.1)$$

where: $t_{c.f.\,i}$ – calculated floor-to-floor time for *i* operation, minutes; $t_{p\,i}$ – floor-to-floor time for *i* operation, minutes; n – batch size, pieces. The more the batch size is, the less calculated floor-to-floor time for an operation is.

The preparatory time ($T_{p\text{-}f\,i}$) is the time for performing works which are necessary to prepare for machining parts at the workplace. This time includes:

1. time for getting the task at the job foreman (an operating description sheet with the part drawing and the machining sequence description);
2. time for getting acquainted with the task;
3. time for getting the required cutting and measuring tools, attachments (for example, a three jaws self-centering or four jaws not self-centering chuck, a drill chuck, a dead or live centre, a fixed or follow rest, collet chuck with collets' set, etc.) in the toolroom;
4. time for delivering the required blanks to a work position (when the delivery of blanks is not centralized);
5. time for installing the required attachments on the machine tool and their adjustment;
6. time for installing the required cutting tools on the machine tool, the adjustment for the demanded sizes when machining two – three trial parts (at machining a batch workpieces);
7. time for giving in the machined parts;
8. time for cleaning the machine tool from chips;
9. time for removing attachments and cutting tools from the machine tool (if they are not used in the next working shift);

10. time for taking the attachment, cutting and measuring tools (which are not used in the next shift) back to the toolroom.

Usually preparatory time takes from 10 to 40 minutes depending on the accuracy and complexity of machining, complexity of attachment adjustment and tool setting.

2. *The size of the shop area*: the more the batch is, the more place is required for storing.

3. Production cost price through incomplete production: the more the batch is, the more work in progress, that higher production cost price. The higher the cost of materials and semi-finished blanks, the more the influence of incomplete production on production cost price.

The batch size is calculated in accordance with the formula

$$n = N\times f/ F, \qquad (8.2)$$

where n – the batch size, pieces; N – the annual programme for manufacturing all parts of all groups, piece; F – a number of working days in a year, days; f – a number of days of a stock for parts storage before assembling, days.

Thus, *N/F* is the production programme per day, piece. A number of days of a stock for parts storage before assembling *f* = 2…12. The more the part sizes (it requires more space to store), the more expensive the material and manufacturing (it requires more money, more credits to pay back), the fewer days of a stock for parts storage before assembling (*f* = 2…5). In practice *f* = 0.5…60 days.

The flow-line production is characterized by product start-up timing period and output cycle time:

$$t_{st}=F_{r\,m}/N_{st}, \qquad (8.3)$$

where t_{st} – start-up timing period, minutes; $F_{r\,m}$ – the actual time arrangement of the equipment for corresponding working shifts of operation, minutes; N_{st} – the programme of blank start, pieces.

The output timing period is also determined in the same way:

$$t_{is}= F_{r\,m}/N_{is} \qquad (8.4)$$

where N_{is} – the output programme of parts.

In connection with inevitable occurrence of faulty parts (from 0.05 % to 3 %) the start-up programme should be more than the output programme within the corresponding share.

9. CALCULATION METHODS OF LABOUR INTENSITY

All calculation methods of labour intensity can be divided into exact and approximate.

1. For *floor-to-floor time* calculation is carried out at mass production when there is no equipment readjustment. For each in-between position the basic and auxiliary time is calculated and after that for each operation (process) piece time is calculated:

$$t_{p\,i} = \Sigma(t_{b\,i} + t_{au\,i}) + t_{m\,i} + t_{o.s.\,i} + t_{r\,i}, \tag{9.1}$$

where $t_{p\,i}$ – piece time of *i* operation, minutes; $t_{b\,i}$ – the basic time of *i* operation (during which working feed is switched on. For lathe turning $t_{b\,i}$ = L/s×n, where L – length of a machining pass, mm; s – feed rate, mm/revolution (mmpr); n – a spindle rotation speed, revolution /minute (rpm); $t_{au\,i}$ – the auxiliary time of *i* operation which is not overlapped with the basic time (blank installation and removal, cutting tool change, adjustment of spindle rotational speed and feed, the accelerated advance of a cutting tool to a work surface, adjustment for the machined size with the help of division collar, switching on the working feed, switching off the working feed after machining just-machined surface, the accelerated tool moving to the next position); $t_{m\,i}$ – time for maintenance of *i* operation (cutting tool replacement when it is worn-out, adjustment of the machine tool after cutting tool substitution, fault correction); $t_{o.s.\,i}$ – time for organizational service of *i* operation (machine tool adjustment, lubrication, chip cleaning), minutes; $t_{r\,i}$ – time for the worker to relax of *i* operation.

Usually auxiliary time averages 25 % from the basic time, but for parts with short processed surfaces up to 300 %, with long processed surfaces – up to 3 %. For multiple-purpose machine tools time for service and rest $t_{s\,i}$ ($t_{s\,i}$ = $t_{m\,i}$ + $t_{o.s.\,i}$ + $t_{r\,i}$) takes 6–10 % of operation time ($t_{op\,i}$ = $\Sigma(t_{b\,i} + t_{au\,i})$); for automatic transfer lines t_s = 10–18 %.

The preparatory time ($T_{p\text{-}f}$) for mass and large-scale production is not calculated, but some of its components are considered for organizational service.

The total labour intensity of *j* machining a part in the designed shop ($T_{p\,j}$) is

$$T_{p\,j} = \sum_{i=1}^{k} t_{p\,i}\,, \tag{9.2}$$

where *j* – part order number in all stock-lists; *k* – a number of operations of manufacturing process performed for *j* part in the designed shop.

2. For *calculated floor-to-floor time* calculation is carried out at a medium-sized and small-scale production manufacturing when equipment readjustment is periodically required:

$$t_{c.\ f.\ i} = t_{p\,i} + T_{p.f.\,i}/n, \qquad (9.3)$$

where: $t_{c.f.\,i}$ – calculated floor-to-floor time for *i* operation, minutes; $t_{p\,i}$ – piece time for *i* operation, minutes; n – the amount of batch workpieces, pieces; $T_{p.f.\,i}$ – the preparatory time which is necessary to install attachments and cutting tools on the machining tool, to adjust them, to set up the machine, to remove attachments and tools after machining batch workpieces at workplace for *i* operation, minutes (it takes from 30 min to several hours depending on the complexity of the machining tool).

Further calculation is done in the same way as for piece time.

3. The *similitude method (comparison method)* is used at single-piece and a small-scale manufacture when the spectrum of work pieces is great and exact calculation will take too much time. According to this method all parts are divided into groups of constructive-technological similarity, in each group the part-representative is selected for which detailed technological process is made and calculated floor-to-floor time is determined. After that calculated floor-to-floor time for other parts in the group can be determined in several ways.

- By *reduction coefficient*

$$T_{c\,j} = T_{repr.} \times K_{red\,j}, \qquad (9.4)$$

where $T_{c\,j}$ – calculated floor-to-floor time of machining the considered *j* part in the designed shop, minutes ($T_{c\,j} = \sum t_i$); $T_{repr.}$ – calculated floor-to-floor time of machining the part-representative (complex part) in the designed shop, minutes; $K_{red.\,j}$ – reduction coefficient of the considered *j* part.

Labour intensity calculation according to the reduced programme was considered in detail in the section "Raw data for shop design".

- *The graphical method* is used when there is insignificant difference in the configuration of parts in the group. The characteristic parameter (for example, the product of part length by its diameter L×d) is determined. For 3 or 5 parts differing in this parameter, $T_{c\,i}$. is determined and the dependence diagram of $T_{c\,j}$. on this parameter (e.g. product $L_j \times d_j$) is drawn. Further, intersection of the calculated parameter (for example, $L_j \times d_j$) with this diagram will give the required labour input of $T_{c\,j}$.
- *The method of using the factory data* is applied when similar parts are processed in other factories or shops.

- By *specific labour input* q_{Tc} – in each group of parts specific labour input (the calculated floor-to-floor time related to weight of the *j* part (W_j) or its volume (V_j)) is determined for the part-representative. To determine labour input of part processing its weight is multiplied by specific labour input ($T_{cj} = W_j \times q_{Tc}$). The method is accurate enough, if accuracy of part processing is approximately identical and identical attachments and machine tools are used.

10. CALCULATION OF THE REQUIRED AMOUNT OF EQUIPMENT AND WORKPLACES

Applying calculation methods of the required amount of equipment depends on the character of manufacture and the demanded accuracy of calculation.

1. For mass and large-scale production, when the form of production organization is non-line production, the calculation is done in the following way:

1. A detailed technological process is made for each part.
2. For each operation the type of the machine tool and calculated floor-to-floor time (for mass production – floor-to-floor time) are defined.
3. Operations where machine tools of the same type are used are grouped (see an example Tab. 10.1, 3rd column) and total calculated floor-to-floor time for all group of operations for machining one part (4th column), for annual programmes of each part (6th column) and the annual programme of all parts of the group (7th column) is calculated.

Table 10.1

Calculation of labour input for a large-scale production
(For example, calculation of machine tools quantity)

Machine tool type	Number (name) of a part	Numbers of operations, №	Summation of calculated floor-to-floor time $t_{c.}$ of operations using the same type of the machine tool (m-t), minutes	The annual programme of a part, N, piece	Labour input of the annual programme of a part, machining on the same j-type m-t, $T_{c\ m\text{-}t\ j}$, minutes	Labour input of the annual programmes of the j-machine tool, $T_{N\ c\ m\text{-}t\ j}$, minutes
1	2	3	4	5	6	7
16K20	The shaft №1	1,2,5,7	2+1.2+3.3+4=11	10000	110000	380000
	The shaft №2	1,4,5	2.4+3.1+8=13,5	20000	270000	
6H82	The shaft №1	3,6	4.2+5.1=9,3	10000	93000	245000
	The shaft №2	2,7	5+2.6=7,6	20000	152000	
2125	The shaft №1	4	1,3	10000	13000	73000
	The shaft №2	5,8	0.8+2.2=3	20000	60000	
The total labour input of the annual programme of all parts $T_{N\ c}$					11633.33 hrs	11633.33 hrs

1. The amount of machine tools of j-type is calculated:

$$C_{c\,j} = T_{N\,c\,m\text{-}t\,j.} / F_{r\,m}, \qquad (10.1)$$

where $T_{N\,c\,m\text{-}t\,j}$ – labour input of machining the annual programme of all parts on the given j-type of the machine tool, hrs.; $F_{r\,m}$, – the actual annual time arrangement of using the equipment at the corresponding amount of shifts m a day, hrs.

2. The demanded amount of machine tools C_{ac} which should be an integer number is assumed. When rounding off with the nearest smaller integer number the overtime of one machine tool should not exceed 10 %. For example, if C_c=10.9 pieces, it is possible to take C_{ac} = 10 machine tools, and overtime will make 9 %. If C_c = 5,6 pieces, it is necessary to take C_{ac} = 6 machine tools since if C_{ac} = 5 machine tools overtime will make (0,6/5) ×100 % = 12 %, that is inadmissible. Overtime is usually compensated by means of increasing the cutting modes, and first of all at the expense of feed rate increase (it influences less on the cutting tool than the cutting speed rate) when increasing corner tool tip radius to preserve the demanded surface roughness. If it is not enough, it is necessary to increase the cutting speed, but it will lead to reduction of cutting tool life. The optimal work equipment efficiency factor ($K_u = C_r/C_c$) makes K_u is 0.9– 0.95.

1. **For the single-piece and small-scale production** calculation is done according to the part-representative or complex part:

- Labour input of machining the *part-representative* for the given machining tool is calculated for each *j type* of the machine tool $t_{c\,f\,j}$, minute;
- The operating ratio of the given type of the equipment is determined

$$\alpha_j = \sum t_{c\,f\,j} / T_{c\,f}\,, \qquad (10.2)$$

where $T_{c\,f}$ is total labour input of machining one part-representative

- The total number of machine tools is calculated

$$C_c = T_{\Sigma N\,c} / F_{r\,m}, \qquad (10.3)$$

where $T_{\Sigma N\,c}$ is total labour input for machining all parts of the annual programme in the group, hrs; $F_{r\,m}$ is the actual annual time arrangement of using the equipment according to the corresponding amount of shifts *m* a day, hrs.

- The amount of machine tools of each *j* type is calculated

$$C_{c\ m\text{-}t\,j} = C_c \times \alpha_j. \qquad (10.4)$$

- The accepted amount of machine tools of each type of $C_{ac\ m\text{-}t\,j}$ of the machine tool is determined taking into account the admissible overtime of 10 %.
- The total accepted amount of machine tools is calculated as the sum of the accepted amount of machine tools of each *j* type

$$C_{ac\ m\text{-}t} = \Sigma C_{ac\ m\text{-}t\,j}\ . \qquad (10.5)$$

Let us consider an example of calculation in the conditions of a small-scale manufacture.

1. A technological process for the part-representative is made in detail (Tab. 10.2 – the representative) and calculation results of labour input for machining each operation are shown in Tab. 10.3 grouping in accordance with the models of machining tools used.

Table 10.2

Calculation of labour input for small-scale manufacture

Model of machin e tool	Number (name) of a part	Numbers of operations, №	Summation of calculated floor-to-floor time t_c of operations using the same model of the machine tool $\Sigma t_{c\ f\,j}$, minutes
1	2	3	4
16K20	representative	1, 2, 5, 7	2+1.2+3.3+4=11
6H82	representative	3, 6	4.2+5.1=9.3
2125	representative	4	1.3
Labour input of machining one part, $T_{c.f.}$, minutes			$T_{c.f.\ repr} = 20.6$

2. The operating ratio of each given *j* model of the equipment is calculated in accordance with the formula (10.2):

$\alpha_{16K20} = \Sigma t_{c\ f\ 16K20} / T_{c.f.\ repr} = 11/20.6 = 0.53;$

$\alpha_{16K20} = \Sigma t_{c\ f\ 6H82} / T_{c.f.\ repr} = 9.3/20.6 = 0.45;$

$\alpha_{2125} = \Sigma t_{c\ f\ 2125} / T_{c.f.\ repr} = 1.3/20.6 = 0.06.$

Verification: $\Sigma\alpha_{m\text{-}t}$ = 0.53+0.45+0.06 = 1.04 ≈ 1.

3. For all parts of the group for which a technological process of the complex part (part-representative) has been made and the calculation of labour input of performing each process has been done (see Table 10.2), we make Table 10.3 which is necessary for calculating labour input of the annual programme of all parts of the group in accordance with the reduced programme.

Table 10.3

Calculation of labour input of the annual programme for machining all parts of constructive-technological similarity group in a small-scale manufacture

№ of part	Weight of part, kg	Reduction factor on weight, K_{wj}	Annual production programme, N_j, pieces	Reduction factor on seriality, K_{sj}	Average grade of tolerance and accuracy factor K_{aj}	Average surface roughness, Ra, microns, and roughness factor K_{Raj}	Reduction factor on complexity, K_{cj}	Total reduction factor, K_{rj}	Labour input of manufacturing one part j, $T_{c.f.j}$, minutes	Labour input of annual programme for manufacturing part j, $T_{N\,c.f.j}$, minutes
1	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***	***11***
0	5	1	1000	1	8→1.5	2.5→ 1.1	1	1	**20.6**	Calculation is not required
1	7	1.25	500	1.12	11→1.0	10→ 0.9	0.66	**0.924**	19.03	9517.2
2	5	1	1000	1	8→1.5	2.5→ 1.1	1	1	20.6	20600
3	7	1.25	500	1.12	8→1.5	2.5→ 1.1	1	1.4	28.84	14420
4	5	1	1000	1	7→2.0	2.5→ 1.4	1.7	1.7	35.02	35020
5	7	1.25	500	1.12	7→2.0	2.5→ 1.4	1.7	2.38	49.03	24514
6	2	0.54	2000	0.97	11→1.0	10→ 0.9	0.66	0.35	7.12	14240
7	7	1.25	500	1.12	11→1.0	10→ 0,9	0.66	0.924	19.03	9517.2
…	…	…	…	…	…	…	…	…	…	…
j	7	1.25	500	1.12	8→1.5	2.5→ 1.1	1	1.4	28.84	14420
							Total: $T_{\Sigma N\,c.f.} = \Sigma T_{N\,c.f.j}$			**50620 hrs.**

After calculating the total reduction factor for each part K_{rj} (column № 9) we should calculate labour input of their machining (column № 10).

For example, labour input of machining part № 1 (j = 1):

$T_{c.f.\,j=1} = T_{c.f.\,j=0\ \text{(a complex part)}} \times K_{r\,j=1}$ = 20.6 × 0.924 = 19.03 minutes.

Labour input of machining of part № 3 (j = 3):

$T_{c.f.\,3} = T_{c.f.\,0} \times K_{r\,3}$ = 20.6 × 1.4 = 28.84 minutes.

The detailed calculation of labour input according to the reduced programme is considered before in section “Raw data for shop design”.

3. Total quantity of machine tools (10.3) is calculated in accordance with the formula:

$C_c = T_{\Sigma N\ c.f.\ j} / F_{r\ m}$ = 50620/4060 = 12.5 piece.

where $T_{\Sigma N\ c.f.\ j}$ – labour input of the annual programme for machining all parts in the group of constructive-technological similarity; $F_{r\ m}$ – the actual annual time arrangement of the equipment used at double-shift working.

4. We calculate the quantity of each machine tool model $C_{c\ m\text{-}t}$ in accordance with the formula (10.4) and fix the accepted machine tools quantity $C_{ac\ m\text{-}t}$:

$C_{c\ 16K20} = C_c \times \alpha_{16K20}$ = 12.5 × 0.53 = 6.6 pieces;

$C_{ac\ 16K20}$ = 6 pieces (over time will be equal 10 %).

$C_{c\ 6H82} = C_c \times \alpha_{6H82}$ = 12.5 × 0.45 = 5.6 pieces; $C_{ac\ 6H82}$ = 6 pieces.

$C_{c\ 2125} = C_c \times \alpha_{2125}$ = 12.5 × 0.06 = 0.75 pieces; $C_{ac\ 2125}$ = 1 pieces.

5. The total quantity of accepted machine tools is calculated:

$C_{ac\ \Sigma} = \Sigma C_{ac\ m\text{-}t}$ = 6 + 6 + 1 = 13 pieces.

3. For flow-line production the quantity of machine tools is calculated for each operation according to floor-to-floor time $t_{p\ i}$ and start-up timing period τ_{st}:

$$C_{c\ i} = t_{p\ i} / \tau_{st}. \qquad (10.6)$$

Before calculating the amount of machine tools it is necessary to synchronize the technological process. *Technological process synchronization* is an equalization of operations length to the value equal or multiple to a timing period.

After making a technological process and normalizing it (calculation of piece time for each operation) the duration of operations is usually various. In this case the equipment where operations with small piece time are performed will stand idle expecting the next part.

There is an example of designing a technological process for machining a part (see Fig. 10.1)

Technological process № 1

Operation 1 (mill-centering)

1. Mill face end 1 and 5 simultaneously.

t_{p1} = 2 minutes.

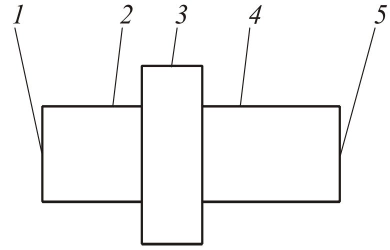


Fig. 10.1. Part sketch

Operation 2 (turning)

1. Turn surface №2.

t_{p2} = 1 minutes.

Operation 3 (turning)

1. Turn surface №3.
2. Turn surface №4.

t_{p3} = 3 minutes.

In technological process №1 duration of operations is various. To equalize duration, it is possible in-between position №1 of the third process to transfer to the second process. Then a new technological process will have identical duration of processes (t_{p1} = t_{p2} = t_{p3} = = t_{pi} =2 minutes) and the timing period can be accepted as equal two minutes (τ_i.= 2 minutes).

An example of a new technological process:

Technological process № 2

Operation 1 (mill-centering)

1. Mill face end 1 and 5 simultaneously.

t_{p1} = 2 minutes.

Operation 2 (turning)

1. Turn surface №2.
2. Turn surface №3.

t_{p2} = 2 minutes.

Operation 3 (turning)

1. Turn surface №4.

t_{p3} = 2 minutes.

Methods of technological process synchronization:

1. Regrouping in-between positions of operations.
2. Changing the cutting modes.
3. Applying for limitative operations (with long floor-to-floor time) cutting tool materials with greater tool life.

4. Applying for limitative operations multi-toothed or combined tools which allow machining several surfaces simultaneously.
5. Making operations on more productive equipment.
6. Reducing stocks. It allows increasing the cutting speed, and decreasing quantity of passes when machining surfaces with very big stocks to (suitable for rough and grinding operations).
7. Applying more perfect attachments that allows decreasing the auxiliary time.
8. Changing a part configuration to improve its fabricability.
9. Applying more perfect transport devices to make installation of the part for the following position (operation) faster.
10. Applying automatic devices to reduce the auxiliary time.
11. Changing technological process radically.

If floor-to-floor time is twice as big as timing period, two machine tools are set in parallel for this operation; if three times bigger – then three machine tools, etc.

4. Calculation of the required amount of equipment in accordance with capacity

$$C_c = \frac{N}{F_{r\,m} \times q} \times K_l, \qquad (10.7)$$

where N – the annual production programme (pieces or kg); $F_{r\,m}$ – the actual time arrangement of using the equipment, hrs.; q – capacity of the equipment (piece/hr. or kg/hr.); K_l – factor of losses for equipment readjustment.

5. Calculation of the required amount of equipment in accordance with technical-and-economic indexes:

$$C_c = \frac{N}{q}, \qquad (10.8)$$

where N – the annual production programme (pieces or kg); q – capacity of the equipment in a year (piece/machine tool or kg/machine tool).

6. Calculation of the required amount of equipment due to percentage ratio to other types of the equipment. Such method is usually used to calculate the auxiliary equipment. For example, the quantity of machine tools for repair and maintenance services is 4 –7 % of the total quantity of the basic production equipment.

11. EQUIPMENT LAYOUT

The department or site layout is a graphic representation of the equipment, machining devices, lift-and-carry units and other means necessary for performing and serving a technological process on the shop drawing.

There are following methods of a layout:

1. *Pattern.* From Whatman paper or a cardboard one cuts out patterns according to the configuration of the equipment placed in the same scale, as the traceable layout of the shop building (usually in scale of 1:50, 1:100, 1:200). It is desirable to have a pattern for each unit of equipment or, at least, for all machine tools placed nearby. All patterns have the machine tool model or the equipment name (for example, "cabinet base ", "workbench", etc.) written on them. After that all patterns are placed on the building layout plan and an optimal variant subject to adherence to the norms of the distance between machine tools and distance from the walls, aisle ways, etc is found. In the computed position the patterns are outlined with a pencil (Fig. 11.1).

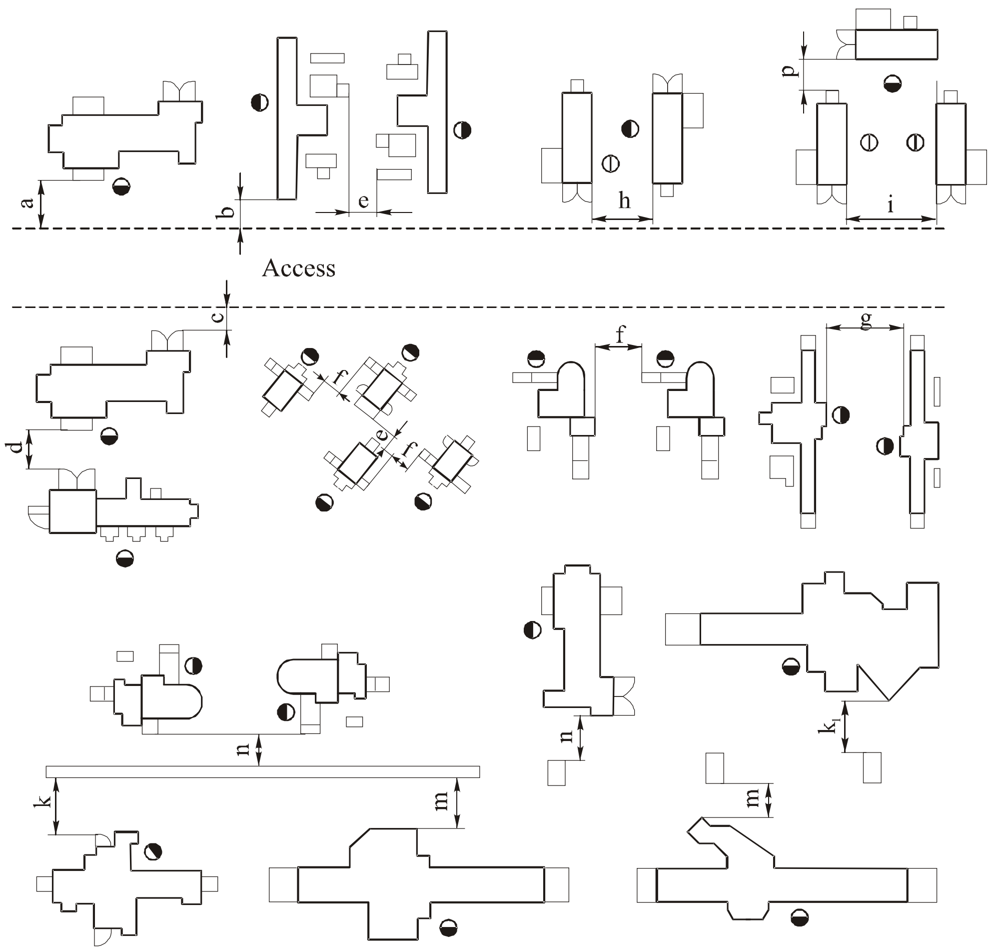


Fig. 11.1. The scheme of machine tool arrangement

2. *Template*. The templates made from a transparent material (usually celluloid) in the factory are used. The templates have the machine tool model and scale (usually 1:100) written on them. The layout of a shop building is performed in the same scale.

3. *Mockup*. Three-dimensional breadboard constructions from plastic or gypsum are used. This method is expensive and used when arranging the equipment for chemical industry and etc., i.e. where there is a link of tubes, tilting furnaces and etc. in space.

When designing a layout the equipment is placed according to the convenience of work and service, aesthetic reasons, technological design norms following the requirements of safety arrangements and precautions (see Fig. 11.1 and Tab. 11.1). Norms are given from extreme positions of moving parts of the machine tool and from open doors of the machine tool, stands and control cabinets.

Table 11.1

Norms of distances, mm (to fig. 11.1)

Distance	Out-to-out measure of the machine tool in the plan, mm		
	To 1800	To 4000	To 8000
From the aisle way (access) to:			
1) the frontal side of the machine tool (a)	1600/1000		2000/1000
2) the lateral side of the machine tool (b)	500		700/500
3) the back side of the machine tool (c)	500		500
Between machine tools when they are arranged:			
1) «in file» to each other (d)	1700/1400	2600/1600	2600/1800
2) the back sides to each other (e)	700	800	1000
3) lateral sides to each other (f)	900		1300/1200
4) the frontal sides to each other and when one worker services:			
One machine tool (g)	2100/1900	2500/2300	2600
Two machine tools (h)	1700/1400	1700/1600	----
Under the ring scheme (i)	2500/1400	2500/1600	----
From walls, columns to:			
1) the frontal side of the machine tool (k)	1600/1300	1600/1500	
2) the frontal side of the machine tool (k_1)	1300	1500/1300	1500
3) the back side of the machine tool (m)	700	800	900
4) the lateral side of the machine tool (n)	1200/900		

Notes:

1. In the denominator there are norms of distances for large-scale and mass production if they differ from the corresponding norms for single-piece, small-scale and medium size production.

2. The distance p between machine tools should be not less than 700 mm in the ring scheme.
3. If there are machine tools of different sizes located close to each other, norms are taken for the biggest one.

All equipment is divided into small (up to 1 ton), medium (from 1 to 10 tons) and large (from 10 to 100 tons). Similar division is used in terms of the greatest outline dimension of the machine tool (see Tab. 11.1).

The width of main access roads for intershop transportation ranges from 4500 to 5500 mm.

The *width of shop aisle ways* depends on the width of a vehicle or the width of a transported cargo:

1. If traffic is one-way

$$A = B + 1400, \qquad (11.1)$$

where A – width of a shop aisle way, mm; B – width of a vehicle or width of a transported cargo (according to the greatest dimension), mm**.**

2. If traffic is two-way

$$A = 2B + 1600. \qquad (11.2)$$

When the width of a shop aisle way is insufficient for any reasons to organize two-way movement and the length of span is big enough, pull-over areas of not less than two lengths of the vehicle with cargo are provided. The distance between pull-over areas is selected from the expediency view point (usually in 25–50 m) or in the places where it is possible to organize them (specific arrangement of the equipment, the extended area of in-process storage, etc.). In front of pull-over areas there is usually a signboard at both sides directing traffic.

The *width of footpaths* is equal to 1400 mm. The *zone of the worker* (from the frontal side of the machine tool to the nape of the worker) is equal to 800 mm.

The examples of layout decisions of machine tool lines are shown in Fig. 11.2. In these schemes the width of footpaths A_2 is equal to 1400 mm (see Fig. 11.2, *a*), the width of transfer tables and racking is B = 670 mm (see Fig. 11.2, *b*), the distance between them is G = 900 mm. The distance between the machine tool and console-based section of the transfer table is D = 400 mm, and the width of a working area between the machine tool and tables is E = 1070 mm. The width K of mechanized inter-stage transport is accepted according to the sizes of fabricated parts, and the distance J between transport devices is not less than 300 mm (see Fig. 11.2, *a*).

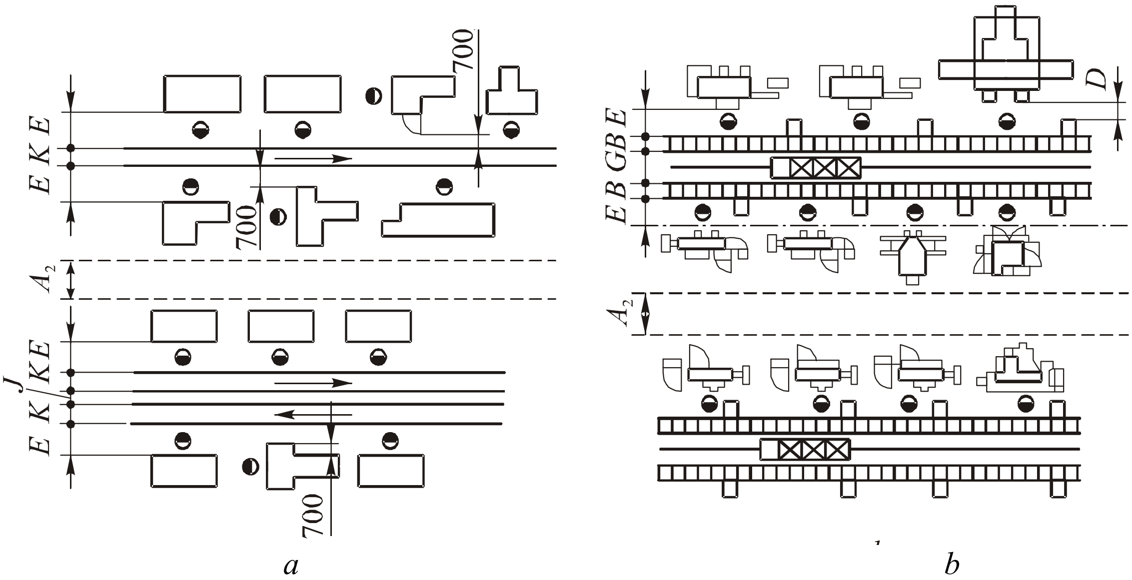


Fig. 11.2. Examples of layout decisions of machine tool lines using various types of inter-stage transport: a – with stationary roller or slatband conveyors; *b* – with the automated storage-and-retrieval system for containers 400×600

Possible variants of arranging stationary assembly stations for single-piece, small-scale and medium size production are presented in Fig. 11.3, and norms on their arranging are shown in Tab. 11.2.

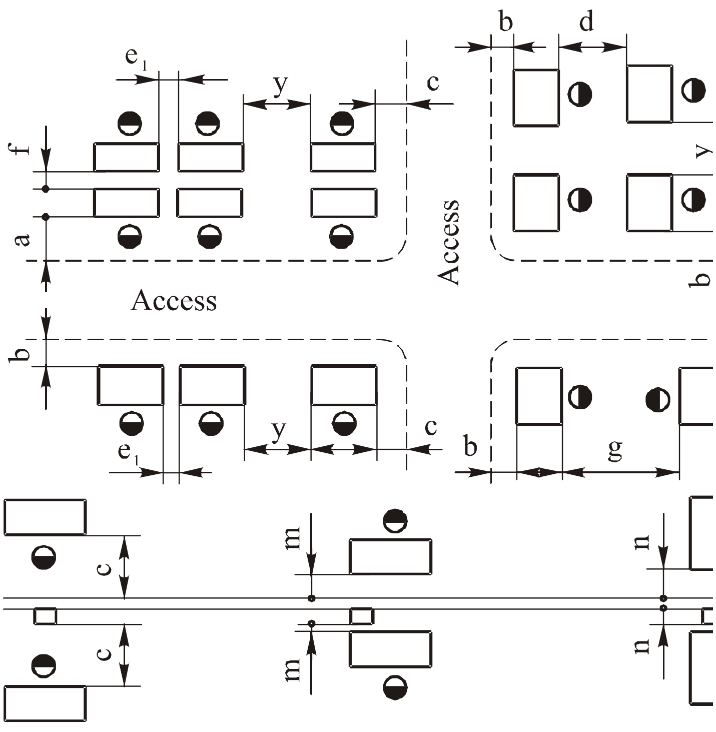


Fig. 11.3. Schemes of arranging assembly stations

Table 11.2

Norms of distances, mm, for arranging assembly stations (related to Fig. 11.3)

Distance	Working area from one side	Working area around the object	
	Overall dimensions of an assembled article, mm		
	to 650×250	to 1250×750	to 2500×1000
From the aisle way to:			
1) the frontal side of a table (*a*)	1500/1000	2250/1000	2250/1500
2) the back side of a table (*b*)	500	1000/750	1000/900
3) lateral sides of tables (*c*)	1250/1000	1000	1000
Between assembly places in case of relative positioning:			
1) «in file» (*d*)	1750/1000	2750/1700	
2) the back sides (*f*)	0	1500/1000	
3) the lateral sides (*e*)	1500/750	1500/750	1500/1200
4) the lateral sides (e_1)	0	1500/750	1500/1200
5) the frontal sides (*g*)	2750/2000	3500/2500	
From walls and columns to:			
1) the frontal side of a table (*h*)	1500/1300	1750/1500	
2) the back side of a table (*q*)	0	1000/750	1000/900
3) the lateral side of a table(*m*)	750		

Notes:

1. In the denominator there are norms of distances for medium size production if they differ from norms for single-piece and small-scale production.
2. The norms do not contain areas for storing parts and assembly units.

Large-scale and mass production is characterized by variants of in-line assembly. In these cases distances for arranging assembly places, as a rule, are defined by an assembly line configuration and the equipment used.

12. GRAPHICAL SYMBOLS OF A LAYOUT

The layout is done in scale 1:100 for small and medium shops, 1:200 – for big shops. Mounting layout with anchoring the equipment to a building is done in scale 1:50. The anchoring can be with a co-ordinate arrangement of the sizes and with a chain one. The co-ordinate arrangement is more precise, but it blacks out the drawing more.

When designing a layout the following factors are considered:

1. Access to workplaces, areas of blanks and parts.
2. Operational comfort of the worker.
3. Convenience of blank delivery to areas of blanks and removal of parts.
4. Closeness of offices for the foreman, quality inspectors, repairmen.
5. Closeness of automatic machines for drink.
6. Closeness of tool-grinding department.
7. Closeness of smoking areas and rest rooms.
8. Convenient location of fire-fighting equipment.
9. All wing doors should open outside according to preventive fire-fighting regulations.
10. There should be free access for fire engines and fast evacuation of people and expensive machinery provided.
11. There should be fast evacuation of crane operators provided.
12. It is not allowed to mix the equipment of various categories of harm and noise.
13. A sufficient air circulation should be provided.
14. Good illumination intensity should be provided.
15. Pipe and conductor lines should be put outside the transport system zone.

When designing a workshop the graphical symbols of a layout are used. The most widespread symbols are shown in Tab. 12.1.

Table 12.1

Symbols of a layout

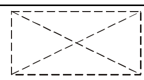
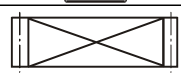
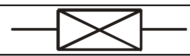
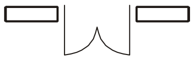
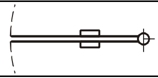
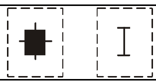
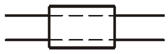
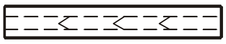
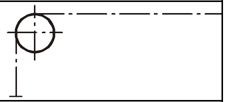
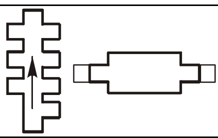
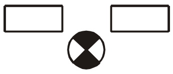
Main walls		Place for storing blanks and articles	
Windows		Control board	
Continuous partitions		Bridge crane	
Partition from glass blocks		Multilayed single-depth racking	
Barriers		Automated stacker crane	

Table 12.1 (continuation)

Hinged gates		Walking crane with electric hoist	
Slide gates		Automated guided vehicle	
Reinforced-concrete and metal columns		Rail-guided cart	
The port for chip transportation		Overhead chain conveyor	
Automatic transfer line and processing equipment		The industrial robot	
Worker's place		Single-row roller track conveyor	
Multimachine service by one worker		Compressed air supply (digits specify pressure in the system)	
Checkpoint		Take-over point of a conductor line to the equipment	

The layout drawing has:

1. Column section with substructure.
2. The main accesses, shop aisle ways and footpaths for people.
3. External and internal walls, partitions, barriers and etc.
4. Windows, gates, doors in open position.
5. Basic and auxiliary equipment.
6. Worker's position.
7. Workbenches, worktables, racks, stands.
8. Places for storing blanks, parts and articles.
9. Places for storing attachments, cutting and measuring tools.
10. Inspection platforms.
11. Foreman's position.
12. Transport devices and facilities.
13. Necessary sections with the cellars, shafts, built-in shelves indicated.
14. The width and length of spans, total length and width of the shop, column spacing are shown; function, width and length of each industrial and auxiliary department; distance from walls and columns to machine tools and distance between machine tools; dimensional specification of large machine tools; equipment numbering with its description in the specification.

13. WORKPLACE ORGANIZATION

Workplace organization depends on:

1. the construction, sizes and weight of machined workpieces or articles;
2. forms of manufacture organization;
3. technological process;
4. manufacture seriality;
5. batch size.

If the part weighs more than 16 kg, the turning crane is used to set it on the machine tool. The crane is usually fastened to nearest column or founded on the individual base. The turning crane usually serves two machine tools, therefore it is necessary to locate them properly. Areas of blanks and parts should be within the area served by crane (usually the area of parts of one machine tool serves as the area of blanks for another). The arm of the turning crane is usually 4–6 m long.

In series manufacturing in the areas of parts and articles when machining small workpieces (weighing less than 3 kg) the pushcarts with containers are set to reduce a number of cargo transshipment at transportation. Large parts are placed in a big container (total weight is several hundred kilograms) which is moved between work positions by a bridge crane, a jib or a loader. The area for such container can occupy some square metres. Very large blanks (weighing hundred kilograms) are placed in stacks.

There is a cabinet for cutting and measuring tools in the operating area of the machine. The tools which are used more often are on the upper shelf, rarely used – on the lower one. In a small-scale manufacture there is a storage cupboard or a storing place for attachments near the machine tool (usually behind the machine tool). These attachments are: for lathes – turning three- and four-jaw chucks, face plates, lathe rests (backrests), turrets for footstocks, personal cutting and measuring tools, for milling machine tools – vises and dividing heads, arbors and adapters (sleeves) for the milling machine tool, for grinders – balanced grinding wheels from various abrasive materials and of various grade on mandrels to be changed fast on the machine tool and etc.).

As for small-scale and single-piece production there can be a cupboard for keeping overalls and outer clothing near the machine tool (usually behind the machine tool). In this case workers do not use the cloakroom.

In Fig. 13.1 a detailed layout drawing of Robotized Technological Complex (RTC) with ring equipment arrangement is shown. There are four NC lathes (*1–4),* two inspection and measuring machines (*7)* and the industrial robot by "Asia" corporation (Sweden) moving within a working area.

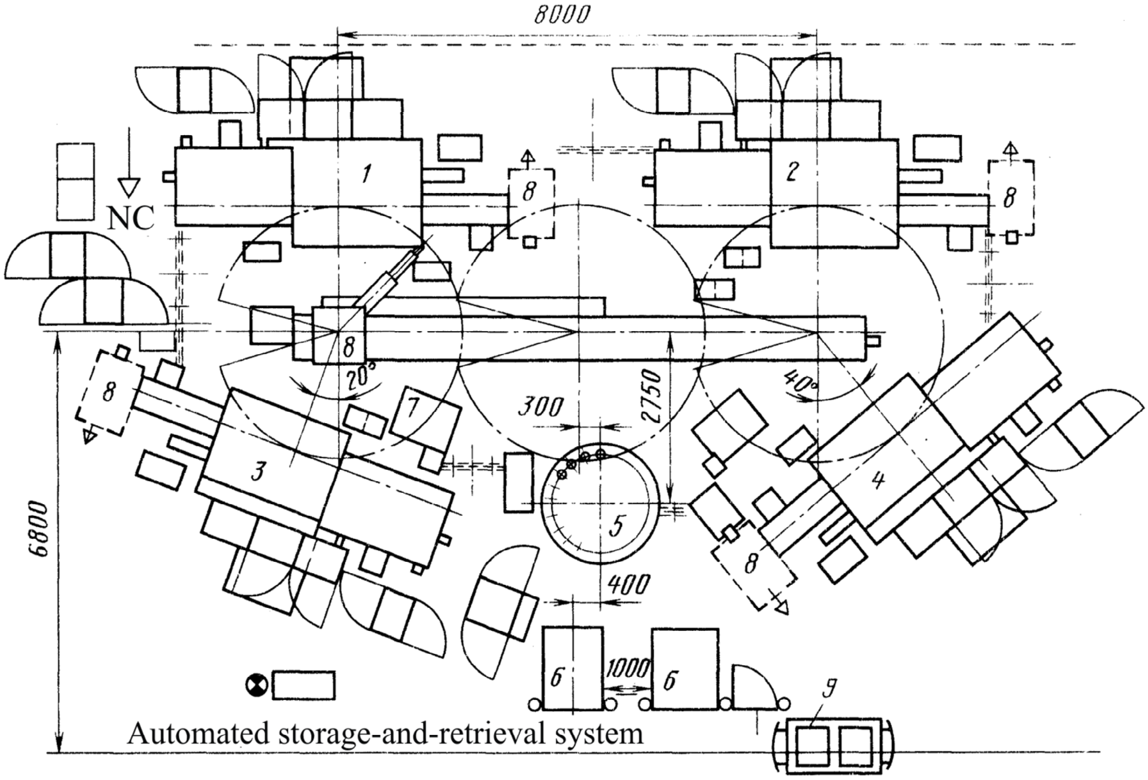


Fig. 13.1. A layout example of a working place (layout of RTC for chucking)

To place blanks and finished parts a three-storied carousel-type magazine (*5)* is provided. Blanks are delivered in unified containers by the transport robot (*9)* from the centralized storage to delivery tables (*6)*. Magazine loading and uploading is executed periodically by an operator-setter serving the location. The chip is stored in the containers (*8)* near the machine tools, and then it is delivered to the collecting point by a mechanized transport. To ensure the safety of workers there is a protection fence around robot operating area provided. The similar layout of machine tools stipulates high requirements for reliability of the industrial robot since it serves four machine tools and any of its refusals paralyzes the work of the whole complex.

When designing mass production flow lines it is difficult to place the equipment of different capacity. In this case different quantity of machine tools and blank flow distribution are provided for contiguous operations. An example of a flow line layout using overhead conveyors as an inter-stage transport is shown in Fig. 13.2.

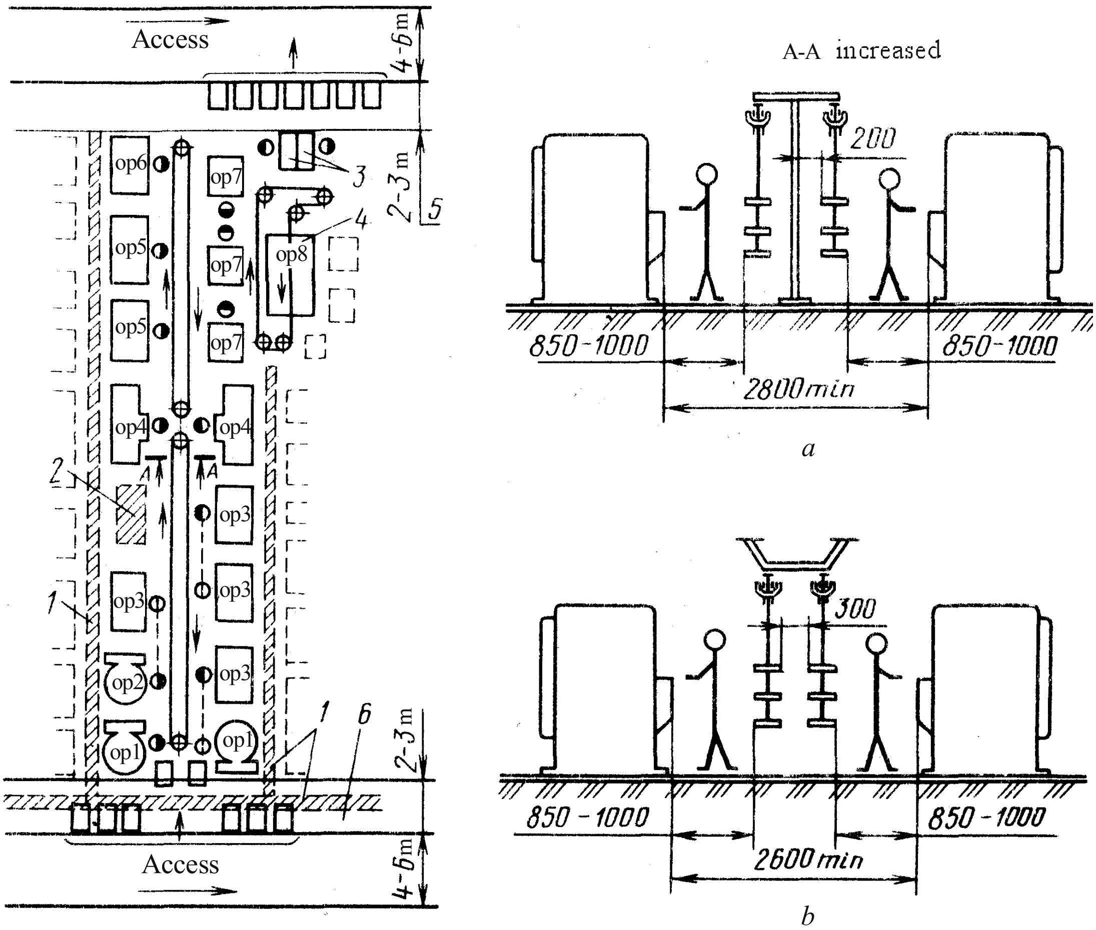


Fig. 13.2. A flow line layout using cable conveyors:
a, b – variants of mounting conveyors

At the beginning of the line there is a zone (*6)* 2–3 m wide to locate the container with blanks. Further two rows of machine tools are located on either side of two overhead conveyors. The conveyors are equipped with multi-shelf suspenders or suspenders with pins, cells and other elements that also allows using them as storage elements. There are three overhead conveyors dividing the line into three sites. There is a reserved place (*2)* at the first site. At the end of the line there is a washer (*4)* and check points (*3)*. In the area of finished parts there is a container with parts to be sent for assembling. Chip removing conveyors (*1)* are provided on either side of the line.

Let us consider some particular layout examples of machining and assembling sites and lines. In Fig. 13.3 and 13.4 the layout of FMS ACB-201 for manufacturing turned components, the flat-shaped and case-shaped parts for series production is shown. FMS is rated at manufacturing 500 part names a year where the batch contains 25–100 workpieces, the total annual output of parts is 66 000 pieces. The sizes of fabricated parts: diameter – 50–500 mm, length – up to 500 mm, width and height – up to 500 mm.

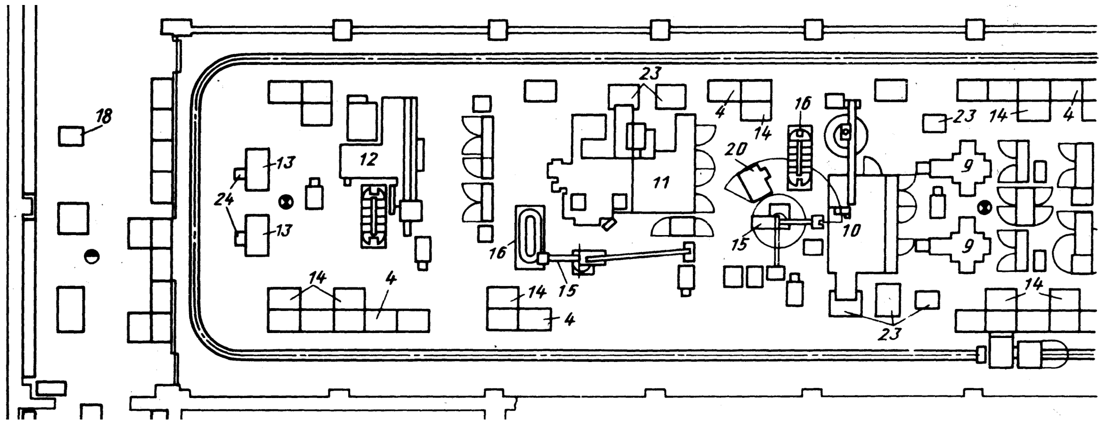


Fig. 13.3. A layout of ACB-201 flexible manufacturing system for producing turned parts in small-scale and medium size production (on the left)

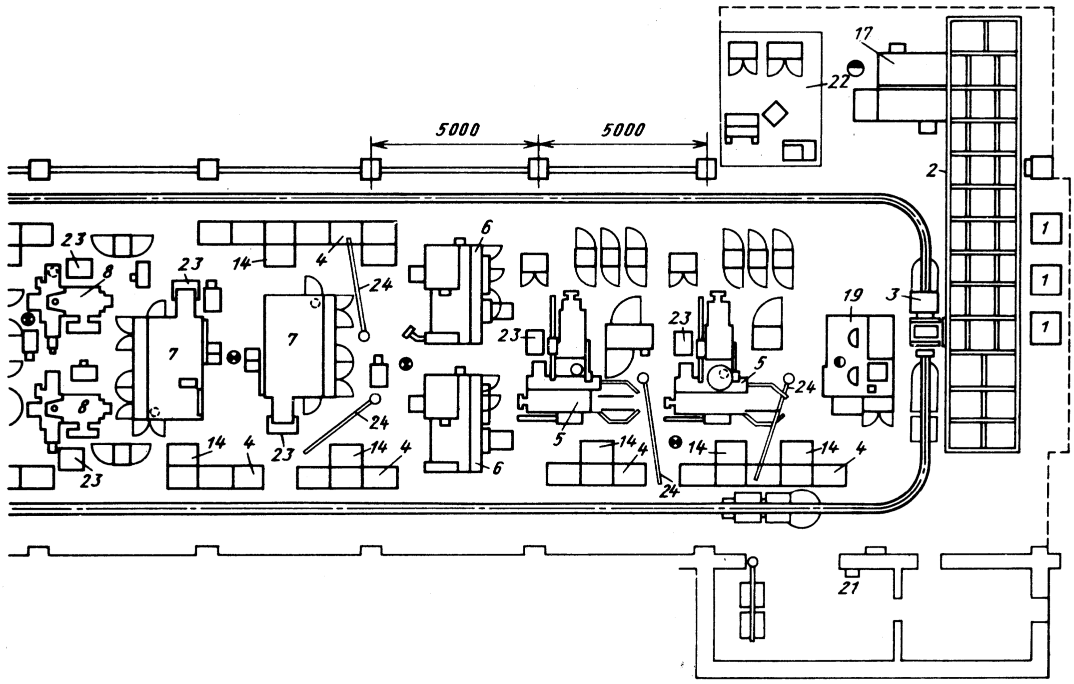


Fig. 13.4. A layout of ACB-201 flexible manufacturing system for producing cased-parts in small-scale and medium size production (on the right)

The flexible manufacturing system consists of 15 NC machine tools including three flexible machining cells (FMC). The combination of flexible machining cells and high-production hand-load NC machine tools ensures high reliability of the system.

Case-shaped parts are fabricated on two multi-purpose machines (*5)* (model IR500PMF4) with interchangeable platens. A blank is fixed on a platen which is free while the machine tool is working. One worker serves two machine tools. Two semi-automatic machine tools (*6)* with chucks (model 1P756PFZ) for machining (chucking**)** turned components with diameter up to 500 mm and two semi-automated machines (*7*) (model MA1P420FZO) for producing parts with less diameter (up to 200 mm) are used. Behind these machine tools there is a group of machine tools for manufacturing plane parts as well as for additional hole machining of slots and flats in turned components – two vertical mill-drill-bore machines (*8*) (model 6T13MF4) and two drill-press machines (*9)*(model 2R135F2) with a turret.

Further there are three flexible machining cells with stepping tables *(16)* – the turning module (*10)* on the basis of MA1P420FZO turning semiautomatic NC machine tool and the robot (*15)* (model MAP.40.01), drill-mill-bore FMC (*11)* and grinding FMC (*12)*(model MA85-1). At the end of the site there are two NC lathes (*13)* (model 1600FZO) for producing small parts.

To transfer blanks, instruments and parts there is an automated storage-and-retrieval system with a centralized four level storage (*2)* with capacity of 64 cells and a closed-type transport system with a transport robot (*3)* having weight-lifting capacity 550 kg. In the operating area of the machine tools there are delivery tables (*4, 14)* for parts and blanks as well as devices for their automatic joining with the transport robot.

The computer complex controls the automated storage-and-retrieval system.

Each workplace has an individual board to connect with a dispatcher who is in the dispatching point (*22).* The dispatcher is responsible for controlling storage-and-retrieval system and ensures timely supply of blanks from the storage to workplaces and their further movements. In the storage area *(17)* blank loading and finished part distribution are provided. The FMS has sections for tools preparing *(18)*, parts inspection (*19)*, accumulators charging (*21)*, containers (*1)* and chip gathering (*23).* In the area of the turning module there is an inspection and measuring machine (*20).*

At such layout equipment is placed in accordance with specialized part groups ensuring total machining of parts with minimum movements. FMS is served by 12 persons per shift including 6 machine workers. To install heavy blanks there are four articulated balanced manipulator (*24)*.

Temperature machining conditions. Quality parametres of parts and articles are influenced by equipment or assembly working conditions: temperature-humidity room conditions, vibrations by the equipment working, etc. Especially great value has the specified conditions by manufacture of high-precision articles (machine tools, tools, precision nodes of the fuel device, etc.). The above-noted conditions are particularly of great importance when manufacturing exacting products (machines, instruments, precision components of fuel units, etc.). Moreover, when designing divisions and shops it is necessary to ensure permissible level of acoustical pressure and illumination intensity that is of great importance for maintenance personnel.

For precision part manufacture the following machine tools are used: A – of high accuracy, B – of particular high accuracy and C – of ultrahigh precision intended for achieving pinpoint accuracy of manufacturing master and drive components of machine tools and measuring instruments. High precision of these machine tools for machining, assembling and position adjusting components and articles can be provided only in such locations which microclimate parametres (temperature, humidity, air velocity) meet the severe requirements (see Tab. 13.1). When conditioning the room there is multiple air exchange within an hour. The combined extract-and-input ventilation stipulates the air flows which speed is restricted within the values specified in the table. Relative degree of humidity 50±10 % should be supported in temperature-controlled rooms since there are high-precision measuring devices on which corrosive attacks are inadmissible.

To prevent outside intrusion of dust the pressure of 1–2 Pa higher than atmospheric pressure is supported in buildings of precision manufacture.

Parts and units received for machining or assembling at sites of temperature-controlled shops should stay there for 1–2 days for equalization of their temperature with local temperature. For this purpose near the equipment and assembly benches there are spacious places provided for storing blanks and parts if there is no temperature-controlled room. For air blow-off and a dust removal from arriving goods and maintenance personnel' clothes there are special gates with vertical air draft at the entrance of temperature-controlled rooms. The access to these rooms is restricted as the presence of the additional personnel can break the temperature condition. The number of doors, gates and external walls should be minimum. Rooms with the most severe condition (20 °C ± 0,2 °C... 20 °C ± 0,05 °C) should be isolated from external walls by a corridor for thermal protection.

Table 13.1

Basic microclimate requirements to mechanical and assembling departments of precision manufacture

Operations	Accuracy rating of machine tools or fabricated article	Temperature allowed deviations, ± °C, from +20 °C at weight of articles, ton		Maximum air speed, m/s
		up to 1	above 1	
1	2	3	4	5
Finished machining of parts: shafts and sleeves, precise holes in case-shaped parts, slides of base components, index gears and disks, screws, wormscrews	B	1.5	1.0	0.3–0.5
Fair grinding, final assembly and inspection of units and machine tools, acceptance inspection and adjustment	A, C	1.0	0.5	0.2–0.3
Preliminary assembling of machine tools and units	B; A; C	2.0 1.5	1.5 1.0	0.3–0.5
Manufacturing precision pairs of fuel and hydraulic units: - finish machining of parts, - assembly, - trial		1; 0.5; 2		0.2; 0.1–0.2; 0.3–0.5
Finish machining of worm milling cutters, gear-shaping cutters, shavers	A; AA; AAA	2; 1,5; 1,0		0.2–0.5
Graduating line standard scale of machine tools	B; A; C	1; 0.5; 0.25; 0.25; 0.1; 0.05		0.2–0.3; 0.1

Note*:* temperature maximum deviations are given for sites of graduating line standard scale with length up to 500, 1000 and 2000 mm.

It is not allowed to place compressors, hammers, presses and other equipment causing vibration near precision machining departments.

To mount machine tools (A and C classes), measuring tools of ultrahigh accuracy, integration benches special vibration isolating bases-stands with greater depth are used.

14. METHODS OF EQUIPMENT ARRANGEMENT AND FLOOR SPACE CALCULATION

The equipment can be located (see Fig. 11.1):

1. *Along the aisle way with front face to it*. In this way the equipment is usually mounted in long and narrow shops. The advantages of such arrangement are a) it is convenient to drive up to the areas with blanks and parts; b) it is convenient to pass blanks to the next machine tool that is very actual when the equipment is arranged according to the technological process sequence (the area of parts of the first machine tool serves as the area of blanks for the second one; at flow-line production transferring is made easier with the help of a slope conveyor or delivery table or conveyor). The disadvantage – it can cause danger from transport behind the worker. To protect from coming onto a road surface suddenly there are barriers in front of the working area.

2. Along *the aisle way with backside to it*. In this way the equipment is usually mounted in long and narrow shops. The advantage of such arrangement is protection from traffic flow. The disadvantage – it is difficult to drive up to the areas with blanks and parts. The equipment is rarely mounted in this way. The preference to such layout is given when there is an assembly line behind the worker.

3. *Across the aisle way «in file» to each other*. In most cases the equipment is mounted in this way; it allows decreasing the length of a division or shop. When using a chip removal conveyor the pipeline transportation of chips runs under the machine tool parallel to the aisle way. The machine tool tray is fixed in the leaning position that prevents an accidentally dropped instrument or a part from getting into the pipeline immediately from where it is almost impossible to get it. To protect the worker who stands in front of the machine tool from chips from the back side of the machine tool there is a protection screen (more often it is made from small metal mesh) fixed. The areas of blanks and parts are located by the aisle way.

4. *Across the aisle way by the frontal sides to each other*. More often the equipment is mounted in this way if these two machine tools are used for multistage machining of the same part. The advantage of such arrangement is the greatest layout compactness, easy adoption of multi-machine manning (when only ***two machine tools*** are served). In this way it is desirable to mount millers and grinders which usually have enough basic time to switch to multi-machine manning as well as semiautomatic lathes. The disadvantage of frontal arrangement is the requirement of psychological compatibility

between the workers of these two machine tools since they can disturb each other.

5. *At an angle to the access with the frontal or back sides.* The advantage of this layout is an east-west mounting with sufficient security of the worker who is in front of it. Such arrangement is typical for single-piece and a small-scale production when the room is not wide enough for east-west mounting. It is good for mounting semiautomatic devices or automatic machines to facilitate loading of long bars.

6. *Under the ring scheme.* It is typical for multi-machine manning – the worker who is in the middle monitors all machine tools easily, he can quickly approach any of them. The amount of machine tools is usually not more than 5. If the equipment has big sizes, it is mounted not under the ring scheme but at an angle to the access (it is a more compact arrangement).

7. *In staggered order.* The equipment is usually mounting in this way when there are large and small machine tools in close vicinity. It allows mounting the equipment more compactly when the shop is wide. The disadvantages of such arrangement are deterioration of an aesthetic aspect as it seems to be chaotic and difficult in driving up to the areas of blanks and parts.

In a shop the equipment can be grouped by using two methods:

1. *According to the technological process sequence*. It is typical for mass, large-scale and medium-size production. At for small-scale production such arrangement is applied when machining in accordance with group technology or machining a wide range of similar parts.

2. *According to groups of technological similarity* (lathes, millers, grinders and etc.). It is applied for single-piece and a small-scale production to facilitate machine tool service by start-up men and to monitor a part lot machining.

If the process of machining parts and assembling an article from them is carried out in one building, assembly and machining lines should be coordinated (for example, from part machining sites №1 and №2 parts should get immediately to position №1 of assembly, from site №3 – to position №2 of assembly and etc.).

To define the production floor space it is necessary to calculate the required quantity of machine tools. The *production floor space* is a shop area where a technological process to manufacture basic products is carried out directly. This area consists of:

1. The place for the machine tool with control stands and power cabinets.
2. The place for cabinets for cutting and measuring tools.
3. The place for a table or a cabinet for monitoring (if it is provided in accordance with the operations).
4. The place for areas of blanks and parts.
5. The place for floor vehicles.
6. The place for footpaths and drives between machine tools (except main accesses).
7. The place for facilities, equipment and other resources necessary for performing a technological process.

The total production floor space

$$S_m = \sum_{i=1}^{n} C_{ac.i} \times f_i \ , \tag{14.1}$$

where S_m – the total production floor space, m^2; $C_{ac\,i}$ – the given amount of machine tools of the given model or type; n – a number of models or types of machine tools used in the production work; f_i – a specific production floor space, m^2/machine tool.

The specific production area depends on a particular model of the machine tool. For integrated calculations the following data is used:

For small machine tools f = 7–10 m^2/machine tool;

For medium machine tools f = 10–20 m^2/machine tool;

For large machine tools f = 20–60 m^2/machine tool;

For very large machine tools f = 60–170 m^2/machine tool.

For small-scale production and small shops the bigger numbers are assumed, for large-scale production and large shops – smaller digits are assumed. Since manufacture is smoothly running, the probability of re-planning the equipment is low, each square metre of the area is rated highly; there is more room for the blank area. Calculations according to the specific area can cause big errors, therefore it is necessary to correct them during the planning process.

15. CALCULATION METHODS FOR EMPLOYMENT SIZE

To calculate the employment size various methods are used.

1. ***Calculation of direct labour.***

- *According to work labour input:*

$$R = T / (F_{r\,w} \times K_m), \qquad (15.1)$$

where R – amount of workers; T – labour input of the corresponding aspect of operations (turning, milling and etc.); $F_{r\,w}$ – the actual time arrangement of workers; K_m – the factor of multi-machine service (it is applied only for multi-machine service). For integrated calculations K_m=1.1–1.35 for small-scale manufacture; K_m=1.3–1.5 for medium-size manufacture; K_m=1.9–2.2 for mass production. This factor can be applied to the following types of machine tools: K_m=1 – for multiple-purpose machine tools; K_m=3–8 – for automatic bar-stock turret machines; K_m=2–4 – for gear–making semiautomatic machines; K_m=2–3 – for NC machine tools.

- *According to workplaces.* The layout is done, and then workers are placed at workplaces and the required quantity of staff is calculated with due regard for shift system and holiday leaves. For flow line production only this calculation method for employment size is used.
- *According to technical-and-economic indexes, or specific output*:

$$R = N / q, \qquad (15.2)$$

where R – amount of workers; N – the production programme (pieces or kg); q – specific output (piece/1 worker or kg/1 worker).

- *According to the percentage of other categories of workers.* For example, milling operations make 5 % of turning operations; if there are 100 lathe operators required then milling-machine operators are equal to 5 persons.

2. ***Calculation of auxiliary labour*:**

- *According to labour input*:

$$R = T / F_{r\,w}, \qquad (15.3)$$

where T – annual work labour input (grinding, inspection and etc.).

- *According to workplaces*.
- *According to service norms.* To service lathes one start-up man is required for 11–18 machine tools; grinding machines – one start-up man for 8–18 machine tools; NC turning machines – one start-up man for 4–10

machine tools; NC drilling and milling machines – one start-up man for 8–16 machine tools and etc.

- *According to the percentage of other categories of workers.* For single-piece production 10–18 % auxiliary labour of direct labour is required, for serial – 18–25 %, for mass – 25–50 %. For single-piece production less start-up men are required since all-round workmen have rather high qualification and can adjust the machine tool on their own. For mass production more start-up men are required since workers, as a rule, have low qualification (high qualification is not required, narrow specialization is applied); it requires more inspectors since 100 % control is applied, it requires more grindermen and etc.

3. ***Calculation of the required amounts of office workers.*** Office workers are engineering and technical personnel (ETP) and office personnel (OP). Engineering and technical personnel include a machine-shop manager, deputy machine-shop managers, subdivision managers, laboratory chiefs, supervising foremen, foremen, manufacturing engineers, designers, technicians, process estimators, economists, workshop mechanic and electrician (power engineering specialist). Office personnel include accountants, cashiers, secretaries, check men, store men.

- *Calculation according to the management system and service norms.*
- *According to the leading enterprises.* This method can cause a big mistake, therefore is used as integrated.
- *According to the percentage of direct labour.* For example, in single-piece production engineering and technical personnel make 18 – 24 % of direct labour, in mass production – from 15 to 20 %. Office personnel make about 5 % on the average. For large workshops (more than 200 workers) the percentage is less, for small workshops – it is more (for example, for 50 workers there should be a machine-shop manager, a foreman, a manufacturing engineer and etc. For single-piece production there are sometimes more engineering and technical personnel than workers. For example, to download a high production NC machine tool several programmers are required when workpiece programmes are small, and one workman services several machine tools.

4. ***Calculation of junior labour (JL)*** is done according to the service norms (one cleaner for 500 m^2) or due to the percentage (cloakroom attendants make 2–3 % of employment size).

16. AUXILIARY SYSTEM DESIGN

The auxiliary system is intended for providing trouble-free work of shop floor production. The auxiliary system consists of seven services:

1. Storehouse service;
2. Transport service;
3. Tool management service;
4. Repair and maintenance service;
5. Quality inspection service;
6. Labour safety and consumer services;
7. Management and production planning services.

16.1. Storehouse service

The storehouse service is intended for accumulating, storing and reorganizing (gathering) goods traffic.

Storehouses are divided **according to their intended purpose** into:

1. ***Storehouse for blanks***. In large shops they, in turn, can be divided into storehouse of *materials* (rolled metal, sheets and etc.), storehouse of *blanks* (cast bars, stamped blank components, preliminary preroughed blank components, cut-pieces made in other shop or divisions), *semi-finished parts* (bought at other places, preliminary preroughed).

In machine building industry tubes, round and profiled iron for getting piece part components are widely used. Piece part components are used for forging or pressing blanks of the necessary shapes and sizes or they are used for direct machining. Therefore, depending on overall production, a mechanical engineering plant has a centralized storehouse of metal with a blank preparation shop or storehouses of metal within engineering shops with a blank preparation section for cutting rolled metal. Rolled metal storehouses are also created within automatic workshops (where bar semiautomatic lathes are used).

To store rolled metal special racks are used; their construction depends on the type of hoisting and transport facilities used in a storeroom. In the simplest variant the racks are mounted on the floor. In this case loading and uploading of rolled metal is done with the help of a bridge, underslung or portal jib cranes (trestle crane). The disadvantage of such storehouses is the big area of storing with considerable volumes of rolled metal, especially when the range is various. Storehouses with cantilever racks have considerably greater capacity, however, racking stacker cranes (see Fig. 16.1) or special loaders with side sliding weight handling device, bridge stacker cranes (Fig. 16.1) are necessary for their service. In the first case the greatest capacity of storing and high level of automation by using computer-controlled stacker-trucks are provided.

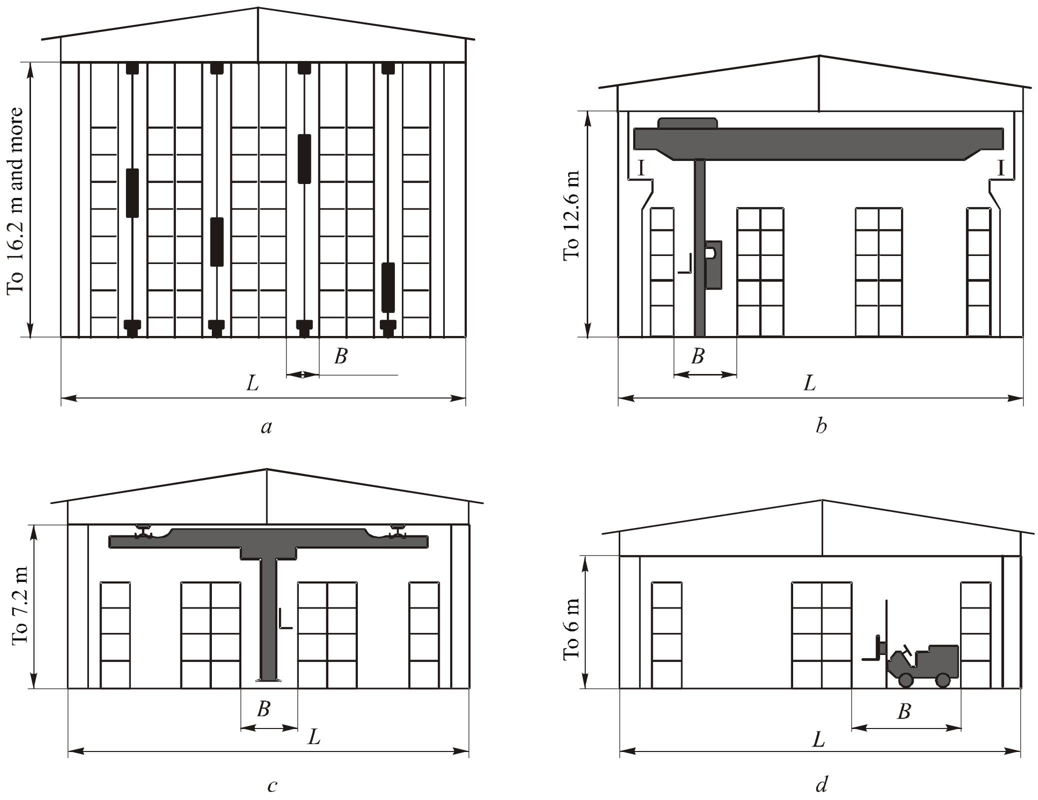


Fig. 16.1. Schemes of racking storehouses when being services: a – by racking stacker crane; *b* – by bridge stacker crane controlled from the cabin; *c* – by underslung stacker crane controlled from the floor or control panel; *d* – by electric lift truck

To cut rolled metal into piece part components there are sawing machines provided with semi-automatic feeders mounted in close proximity to the racks in the storehouse. Therefore each portion of rolled metal from the storehouse is uploaded by the stacker crane or bridge stacker crane directly onto the feeder. Such scheme is used for automated storehouses of rolled metal.

Piece part components and also cut-off rolled metal are stored in containers. Using unified containers is very convenient for transporting from one plant to another or between different buildings of the same plant. Part components in box containers are convenient for storing in *a stack* in some tiers, and applying box trays with an opening upper part of one of the walls allows taking parts from the lower trays of the stack, without removing the upper trays.

Large and heavy castings, welded constructions are stored in stacks as well as part components of the identical spectrum in small store rooms. Palletizing is done with the help of floor-level electric lift trucks, which high maneuverability and gripper fork height provide laying down five tiers of trays with part components in a stack. It is a very economic storehouse type for small shops.

For medium and large shops, especially when the spectrum of part components is large, it is more rational to store part components *in containers on racks*. Schemes and parametres of cellular racks are shown in Fig. 16.1 and in Tab. 16.1.

Table 16.1

Basic parametres of racks without shelves and frame racks in accordance with GOST 14767—81

Racks	Cell length A, mm	Rack width B, mm	Load on a cell, N
Without shelves	450; 710; 950; 1320; 1800;	450; 670; 850; 900; 1120; 1250;	500; 1000; 2 500; 5 000;
Frame	450; 950; 1320; 1800; 2650	450; 670; 850; 900; 1120; 1250	10 000; 20 000

Note: the height of racks H, m, is as follows: 1.8; 2.4; 3.0; 3.6; 5.1; 5.7; 6.3; 6.9; 7.8; 8.4; 9.3; 9.9; 10.5; 12.3; 14.4; 16.2.

Racking without shelves has bearing slides corresponding to the applied containers and in frame racking each cell can contain several trays on the shelf.

2. ***Storehouses for auxiliary materials.*** These storehouses are intended for storing lubricants (oils of various brands), cutting fluids (CF) and their concentrates, wash fluids (kerosene, solar oil, gasoline and etc.), wiping materials (tack cloth, wiping rags and etc.), tiding-up materials (sawdust for removing the oil spilt on a floor). Sometimes such storehouses are named *combustibles and lubricants storehouses* (*CLS*). In small shops store rooms for auxiliary materials are located in storehouses for blanks in separate boxes made from nonflammable material and with an iron door. Special attention is given to a good exhaust ventilation system and active fire alarm equipment reacting to smoke and temperature rise. *Combustibles and lubricants materials* are stored in hermetically sealed containers (more often in metal drums) in small volumes. The basic stock is stored in a factory storehouse or outside of the building shut with a wire fence, under a shelter or in an attached location. If a storehouse for auxiliary materials is inside the building, it is located at the beginning of the shop in order to avoid transportation of fire-dangerous loading around the whole department. The auxiliary material storehouse doors should not open on the entrance, exit and main access road; otherwise the fire will cut off the escape routes.

3. ***Store rooms for in-process storage (intermediate).*** These storehouses are intended for storing part components in-between processes when lying there for more than one day. These rooms are located along the walls near the working positions where part components were machined or will be machined. Sometimes (for inexpensive part components) these store rooms look like *areas for inter-process storage* in the shop territory.

4. ***Store rooms for finished parts.*** These rooms are intended for storing finished parts after machining or before assembling.

5. ***Store rooms for finished articles.*** These rooms are intended for storing finished articles after assembling before transporting to the central factory storehouses.

6. ***Store rooms for production accessories and instruments.*** These store rooms are usually related to tool management service.

According to the form of storing storehouses are divided into:

1. ***Stacking.*** Trays with parts are put on each other (up to 5 trays). This type of storing allows to save room, but it does not allow to take the lower trays quickly (transfer is required); therefore there should be trays with identical parts in a stack.

2. ***Racking.*** Storing parts (containers, part components, tools and etc.) takes place on racks that saves room and allows taking any part or the container (Fig. 16.1) quickly. When loads are heavy (weight is more than 25 kg) electric hoists or loaders (if weight is more than 100 kg) are required. Racking storehouses differ *on height of loading*:

a) small height (up to 5 m, however optimum height of storage is to 2.5 m);
b) medium height (from 5 to 8 m);
c) big height (from 8 to 12.5 m).

Racking storehouses are more spacious in comparison with store rooms where part components are stored in stacks; they occupy less space, and also give a chance to automate storehouse operations. Besides, high construction stability ensures operations safety. Racking storehouses are especially effective when there is a big range of part components or semi-finished products. Moreover, each product has its own zone of storage that ensures order and efficient organization of storehouse operations.

The disadvantage of racking store rooms is their small adaptation to layout changes since the special groundworks with embedded parts are required to build a similar store room. Therefore when creating and arranging similar store rooms it is necessary to take into account prospects of the shop development and the factory in whole.

The basic types of racking storehouses for banks and semi-finished products by using various types of lifting and transporting equipment are shown in Fig. 16.1.

Comparing four introduced variants according to storage capacity with width of the span L = 18 m shows that if storage capacity being serviced by electric lift truck is assumed as one unit, storage capacity being serviced by a bridge crane controlled from the cabin will make 1.27, by the crane controlled from the floor – 1.64, and by the racking stacker cranes – 1.75. It is explained by the smaller width of aisle ways B and also greater height of racks when using the types of transport mentioned above.

For example, an electric lift truck controlled by computer has hoisting capacity of 1000 kg at a height of 5600 mm where the loading is lifted. The electric lift truck is equipped with three-edged loading platform so it can be used in storehouses whose aisle width between racks B = 1700 mm.

When using bridge, overslung and racking stacker cranes the aisle width between racks is 2310–3230 mm, depending on the model and weight-lifting capacity of the stacker at frontal loading, and 1700 mm – when there is a three-edged loading platform. The height on which the weight is lifted makes 3000–5600 mm.

When using bridge, overslung and racking stacker cranes the aisle width between racks is 950 – 1400 mm; constructions of the automated storehouses for flexible manufacturing systems have variants of store rooms with aisle width of 500 mm.

In the area of receiving and delivering loadings there are additional reloading devices provided in store rooms to transfer from external transport to storehouse system devices. Here storage devices which serve for eliminating non-uniformity of external and internal goods traffics are also provided. When part components and semi- finished products are in storage devices, the processes of inspecting, counting, sorting and kitting batches for machining or laying down on special technological container or on palletized carrier are carried out. A palletized carrier is a metal plate which is transported together with the attached workpiece to be mounted on machine tools for machining without displacing technological bases (on the bottom surface of the plate there are holes for attachment fingers fixed on machine tools).

To mechanize lifting and transportation operations in the load-and-unload area it is rational to use articulated balanced manipulators. They are manually controlled balanced multilink manipulators (Fig. 16.2, *a*). These manipulators are produced with a pneumatic and electromechanical drive gear with weight-lifting capacity of 40 – 250 kg and working radius up to 3.1 m.

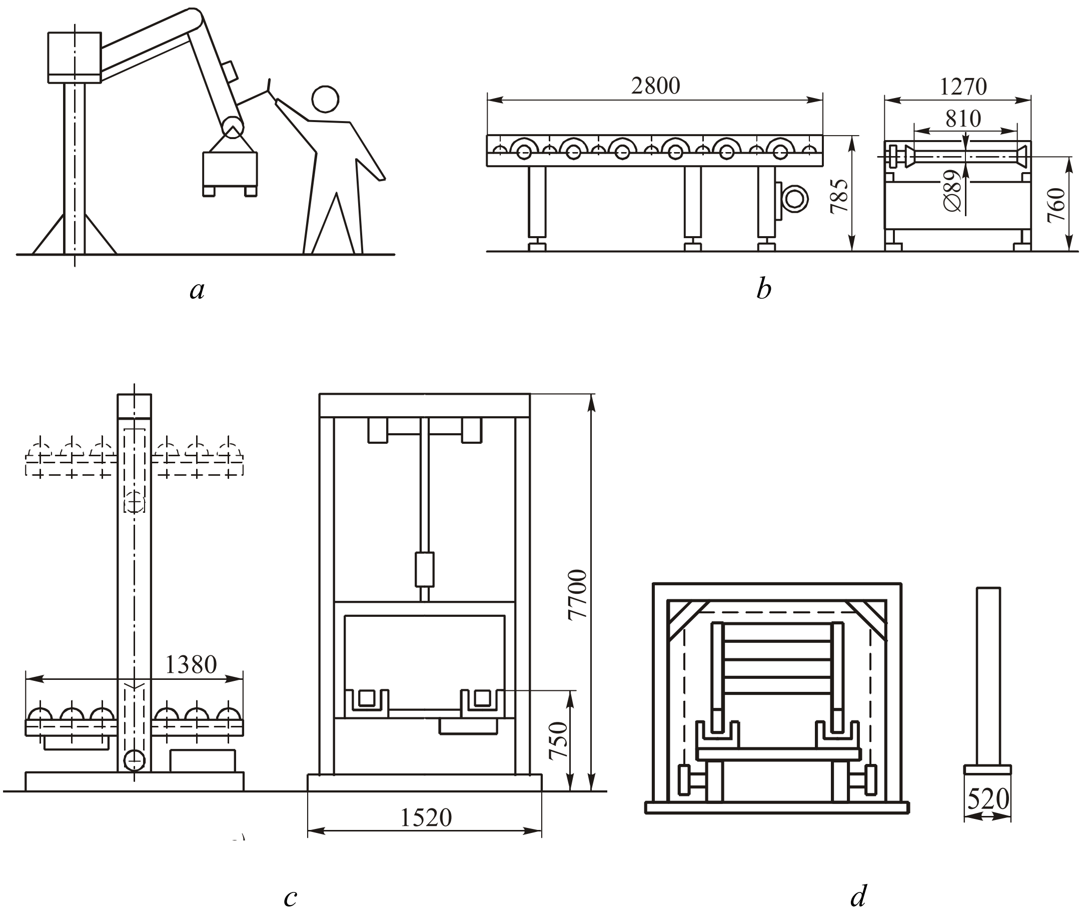


Fig. 16.2. The equipment for receiving and delivering loadings in storehouses: a – the articulated balanced multilink manipulator; *b* – the pick-and-place rolling powered conveyor; *c* – the hoist; *d* – the inspection section of overall dimensions

To transfer trays from the unload area to the storage area roller-track conveyors are used (Fig. 16.2, *b*). They can turn on hoists (Fig. 16.2, *c*), sections of automatic weighing and inspection of overall dimensions (Fig. 16.2, *d*). When the goods traffic is restricted, the area of receiving and delivering loadings is serviced by means of the stacker cranes serving the storage area. However, automating storehouses is usually connected with the equipment having exact functional purposes.

In general, two variants of storehouse arrangement with reception, storage and delivery areas are applied in machine shops (Fig. 16.3). In most cases the deadlock scheme is used: areas for receiving and delivering part components are located at one end of the storehouse. In this case the storehouse is more compact, there is a convenient transmission of empty containers from one site to another, and the same workers can serve both sites. Transmitting trays with part components to machining sites is done by means of floor or overhead conveyors. Advantages of the second variant are the best coordination with manufacturing area arrangement since in this case delivery areas are combined with the beginning of corresponding part manufacturing lines. In each case the selection of the arrangement storehouse scheme should be coordinated with the common shop arrangement and the accepted transport system.

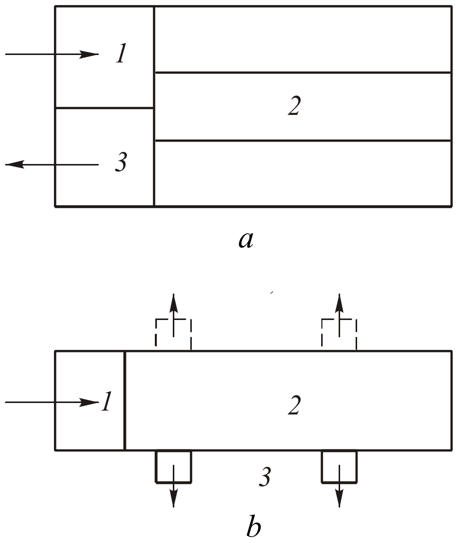


Fig. 16.3. Variants of storehouse arrangements with areas for receiving 1, storing 2 and unloading goods 3: a – deadlock arrangement; *b* – twist-and -steer arrangement

3. ***Conveyor.*** Goods in a container are suspended to a *handover conveyor* (usually closed in a circuit), and when it is switched on, it moves the containers to the storekeeper. There can be several conveyors for different groups of parts. The advantages of such storehouses is that the storekeeper does not have to go around the store room selecting parts; besides, only one turning crane is required in the place where conveyors move for lifting heavy parts or containers. In large store rooms a conveyor system can be organized: there is a mother belt conveyor and across to it there are linear belt conveyors on which containers or boxes with parts (usually used for assembly sets) are put. Short-term switching-on of these or those belt conveyors results in the required amount of containers of the required assortment getting to the mother belt conveyor. The disadvantage is that it requires a big area for arranging all these conveyors.

According to the level of mechanization storehouses are divided into:

1. ***Nonmechanized.***

2. ***Mechanized*** (manually-controlled mechanical devices are used: articulated balanced multilink manipulators, electric hoists, jibs, turning cranes and etc.).

3. ***Highly mechanized*** (bridge cranes, lift trucks, racking stacker cranes, etc. are used).

4. ***Automated*** (first selecting the demanded assortment and amount on the computer, and the automatic stacking loader takes the required parts from the rack). They are used in the central factory storehouses of the advanced enterprises very rarely).

5. ***Automatic*** (the demanded assortment and amount is determined by the computer due to the given programme in accordance with the technological process. They are aimed at method for unmanned manufacture).

According to work methods storehouses are divided into:

1. ***Storage warehouses.***
2. ***Picking storage locations*** (an assembly set for the assembling team is put in one or several containers).

The storehouse service should cooperate well with the transport service:

1. The unified container should be used (in order not to reload goods after transportation from one type of containers in another for storing).
2. The loading and transportation services should be perfected.
3. There should be an optimum arrangement scheme of store rooms in relation to manufacturing areas and transport system. For this purpose storehouses with a twist-and-steer arrangement scheme can be used, not with deadlock, one.

16.2. Transport service

According to the *purpose* the transport service can be:

1. ***Intershop*** (load carrying vehicles, electric cars, railway trucks, auto- and electric fork lift trucks).
2. ***Intrashop*** (electric cars, fork lift trucks, jibs, platform trucks, bridge cranes, railway trucks).
3. ***In-process*** (conveyors, slope tables or conveyors, receiving-delivery tables, roller conveyors, platform trucks, electric cars, fork lift trucks, turning cranes, jibs, bridge cranes).

According to the *method of loading – in containers* and *without containers*. Heavy and large-sized parts (more than 100 kg) are transported without containers although they can also be place in a big container. The preference is given to loading into the container. If parts are small, the weight of the container with parts should not exceed 16 kg (in extreme case no more than 25 kg) since such container is convenient enough for carrying by hand: it is not too bulky and it is easy to get a part from it. If parts are rather large and heavy, the sizes of container are defined by the easiness of taking parts from it (container depth is not more than 600 mm, its width – not more than 1000 mm), and the weight is defined by weight-lifting capacity of the lifting mechanism since such containers are not lifted by hand. In industries very big containers are sometimes applied (depth more than 1500 mm), in which parts are simply thrown, but it is rather difficult to get them from there, besides the parts can have impact damage.

It is better to place parts in the container carefully, instead of *in piles* since in this case the probability of damage is less. The container with wooden support assembly coated with velvet or other tight fabric can be applied for grinded and cleaned parts. Large-sized parts can also be transported on trays with wooden support assembly. Complex case-shaped parts can directly be transported with palletized carriers which allow saving constancy of technological bases when machining.

According to the *routing* transport systems are divided into *linear* (slope tables or conveyors, receiving-delivery tables and etc.) and *closed* (conveyors), and also *branching* and *non-branching*.

According to the *level of positioning a loaded strand* transport systems are divided into *floor conveyors* (electric cars, platform trucks, floor-type conveyors for heavy and large-sized parts and articles), *trestle-type conveyors* (at waist height) and *overhead conveyors* (a loaded strand of the conveyor is positioned above person's height, and part components are suspended from it at head height). *Trestle-type conveyors* are more convenient for part components removal, but they make it difficult to transport around the shop. *Overhead conveyors* block up a location less, but they are very noisy because of chain drive.

Conveyors are applied in flow-line production and divided into *step-motion*, *slipstick* and *uniform*.

When possible it is necessary to reduce goods traffic volume. For this purpose:

1. machining sites should adjoin the assembling shop in the order of demanding parts of the spectrum;
2. storehouse for blanks and semi-finished products should be located in machining buildings;
3. it is necessary to move loads in containers with optimal capacity;
4. it is necessary to reduce the number of transfers (for example, empty containers are on the platform truck and after they are filled up the

platform truck is transported to the proper place without additional reloading);

5. to place the equipment according to the technological process;
6. when possible, to use short chains: receiving-delivery tables, slope conveyors (sloping shoots), roller conveyors;
7. to mechanize loading-unloading operations (turning cranes, articulated balanced manipulators, loaders, electric cars with a hoisting crane (Fig. 16.4), power lift trucks, bridge cranes and etc.);
8. to reduce vertical positioning of loads (to use transferrable bogies with containers, loading from a ramp located at the level of a carrier vehicle platform and etc.);
9. to reduce the number of branching and intersections of the transport system.

Automatic monorail systems are used in shops and divisions of machine-assembling manufacture for transferring articles on-line, for «over flow» transport operations, for feeding articles from flow lines to store rooms and etc.

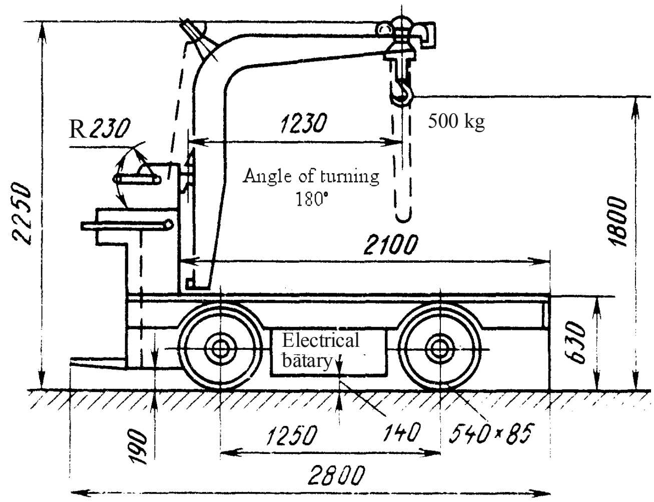


Fig. 16.4. The electric bogie with a hoisting crane

Dual-duty overhead conveyors are finding an increasing application because they allow transporting the articles having various output cycle times. Besides, dual-duty overhead conveyors are used if in the manufacturing process there are limitative operations which runtime is considerably bigger than the runtime of other operations. They ensure automatic delivery of trolleys with a load to their destination, and also a possibility of transferring trolleys to branches of monorail conveyors where they can be either automatically stopped (and then a concentrator can be created from these trolley loaded) or transferred further to a route of other dual-duty overhead conveyor. It gives a chance to link all dual-duty overhead conveyors of the shops in the common system of conveyors with automatic delivery of loads to their destination. Workpiece motion control can be done with the computer.

The peculiarity of the dual-duty overhead conveyor is that in its system there is not one monorail track with trolleys, but two: one track (upper) conveys driving elements, and the second (lower) – the fixed loads.

The system of automated dual-duty overhead conveyors is rather complex, however, its application considerably increases transportation capacity when performing hoisting-and-conveying operations. As the mother conveyor and also for transferring turned parts (flywheels, flanges, pinion gears and etc.) within a site tray-type transporters, where part are transferred with floating movement under action of gravity or more rarely with sliding movements, are used in flow-line production.

Open trays are applied for transferring light articles at insignificant height, and closed trays – for transferring heavy articles over a workplace to meet safety requirements. In fig. 16.5 a tray-type transport system of an automatic workshop is shown.

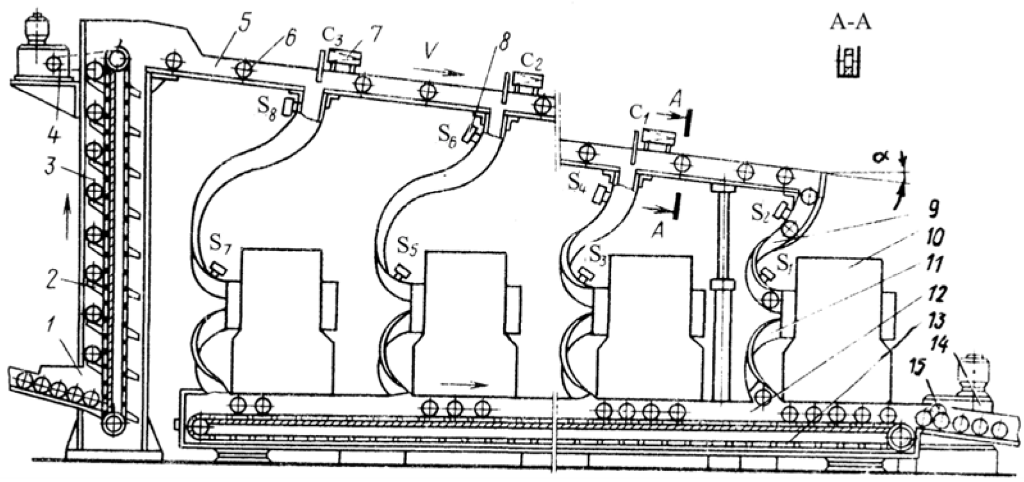


Fig. 16.5. The scheme of a transport system of the turning division of an automatic workshop: 1 – a receiving tray; *2* – lift conveyor grippers; *3* – the hoist; *4* – a lift conveyor drive gear; *5* – a distribution conveyor tray; *6* – part components; *7* – lids; *8* – overflow censors of feed trays; *9* – feed trays of machine tools; *10* – machine tools; *11* – output trays of machine tools; *12* – a run-out conveyor; *13* – a conveyor rolling-bushing chain; *14* – a branch conveyor drive gear; *15* – an output tray to the following site

The transport system in Fig. 16.5 consists of the hoist *3* with a drive gear *4,* the distribution conveyor tray *5*, feed *9* and output *11* trays, a run-out conveyor *12* with a drive gear *14* and system control electrics.

The conveyor works in the following way. Part components getting in the chain hoist *3*, move to a distribution conveyor tray *5*; rolling down these trays to feed trays *9*, part components are delivered to machine tools *10*. After passing the circle of output trays *11* and the conveyor *12* part components are moved to the following site.

When designing and calculating a transport system the arrows are drawn on the shop arrangement and their width is proportional to transportation volume (Fig. 16.6) and their volume (pieces per shift, tons per day or tons per year) is also indicated.

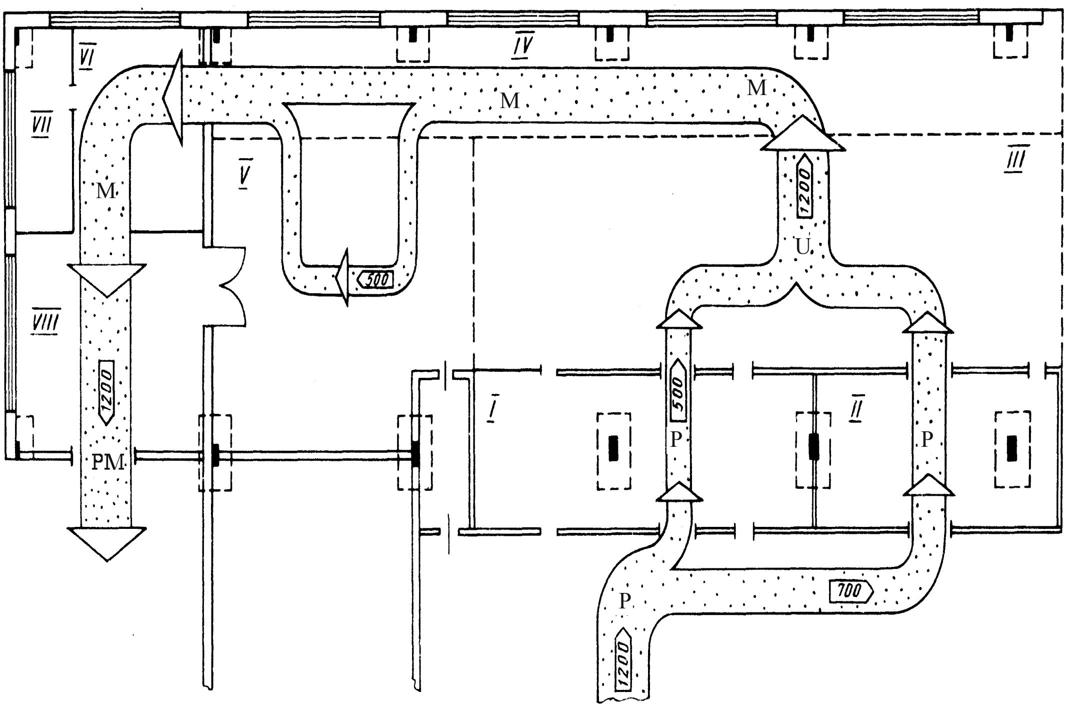


Fig.16.6. The scheme of transport links of the assembling shop: I – a store room for finished parts; *II* – a site for paintings case-shaped parts; *III* – a site for assembling units and kits; *IV* – a site for assembling machines; *V* – a site for testing and adjusting machines; *VI* – a site for painting and adjusting machines; *VII* – a site for preparing paints; *VIII* – a site for kitting and packaging; *goods traffic*: *P* – separate parts; U – the assembled units; *K* – the assembled kits; *M* – the assembled machines

When designing it is necessary to coordinate time, therefore the delivery schedule is made; the size of supplied batch workpieces is calculated. At non-line production it is much more difficult to forecast the labour input of transport operations and it is usually determined in accordance with the formula

$$T = \frac{Q \times t_c}{q \times 60}, \qquad (16.1)$$

where T – labour input of transport processes, hrs.; Q – a goods traffic, tons/yrs.; t_c- average duration of a transport cycle, minutes; q – the size of an average transport batch, tons.

Transport system electrics are aimed at coordinating the operation of the central hoist with operations of machine tools, and also at advance warning and protecting mechanisms from possible breakages when feed trays are overflown.

In flow-line production when manufacturing medium-sized articles (cars, tractors, general-purpose machine tools and etc.) electric bridge cranes, as a rule, are not applied, except for special cases of producing extra heavy articles. This is explained by the fact that additional staff of crane operators is required, and also that fine adjustments of articles by a bridge crane demands much more time than by a turning crane. If it is necessary to adjust parts, part components or articles on several units of equipment simultaneously, it takes extra time to wait for the crane. Besides, crane spans are in need of a high building, and consequently their construction costs more than building without crane spans.

The approximate positioning time plus time for unloading articles weighing up to 150 kg by using an electric bridge crane (including the time for calling it to the place of work) is 3 – 5 minutes; an overhead crane – 0.5 minutes. Overhead cranes are especially expedient to use when serving a certain manufacturing area, instead of a conveyor line.

To increase movement safety there are continuous strips of yellow colour on the shop floor indicating sites with busy traffic. On busy sites there are barriers set preventing people from going onto the aisle ways unexpectedly, there are signs notifying about the danger, crossings marked even traffic lights mounted. The speed of ground transport should be less than 80 m/min, and handover – 50 m/min because of response rate.

16.3. Tool management service

The tool management service is intended for providing instruments and inspecting whether they are used correctly. Exceeding the cutting speed or feed rate causes fast reduction of tool life, consequently – increase of its consumption. Exceeding allowable wear results in fast reduction of tool life, increase of tool removed layer from the tool surfaces in the process of resharpening.

Functions of tool management service are:

1. organizing tools transportation ;
2. storing tools and component elements in a storehouse;

3. adjusting complex tools for the demanded size (cutting tools in blocks for NC machine tools, boring blocks, multicutter blocks, a kit of milling tools on a mandrel and etc.);
4. replacing disposable inserts (throwaway-insert tool bits) on complex tools (face mills, ejector drills and etc.);
5. restoring tools by means of resoldering inserts;
6. cleaning and sharpening tools;
7. assembling and demounting complex tools;
8. inspecting the condition of tool cutting edges;
9. inspecting abrasive wheels and their balancing.

Structure of tool management service:

1. tool storage rooms and factory storehouses;
2. tool-grinding departments and sites (if there is centralized sharpening for large shops);
3. tool shop (for manufacturing complex tools and attachments);
4. workrooms for repairing attachments and cutting tools;
5. sites for assembling and adjusting;
6. a site for soldering cutting plates (on the equipment with high frequency current);
7. a site for coating cutting tools;
8. check points (for inspecting cutting and measuring tools).

Standard cutting tools are bought or ordered at instrument factories; special cutting tools are made in a tool shop or ordered at instrument and other factories.

The tool shop, as a rule, has multiple-purpose equipments with the highest accuracy (lathes, milling, drilling, planing and slotting, grinding tools and etc.) and special equipment (coordinate-boring machine tools, horizontal boring-and-turning mills with a copy facility, evacuated capsules for nitrocarburizing, wear-resistant coating equipment, equipment for soldering cutting plates and etc.), workers with the highest qualification. In large factories the tool shop has its own thermal division. The tool shop condition defines the ability of the enterprise to reorganization, possibility of manufacturing new and complex products.

Methods of replacing cutting tools:

1) *according to refusals,* when cutting tools are replaced after approaching maximum permissible wear. The criteria of maximum wear can be: a) land width of the face of flank wear (when machining steel – no more than 0.25 mm for semi-finishing operation and no more than 0.75 mm for roughing operation); b) deterioration of surface undulation; c) fast change of

the adjusted size (the size "does not keep"); d) whistle or vibration occurrence; e) occurrence of dark blue chips for the high speed steel tools and red ones – for cemented carbide tools and etc.

2) *mixed* or *forced replacement* ,when tools are replaced within a definite period of time which is equal to cutting tool life, without regard to its wear degree. This method of replacement is applied for flow-line production and automatic transfer lines, and cutting conditions are usually selected in such way that cutting tool life is equal or multiple shift length. If the tool wears out before the planned period, it is immediately replaced. If on the automatic transfer line the cutting tools are replaced due to refusals, the line will stand idle more than work (one machine tool is in need of replacement, then the other after a while and etc.).

For uninterrupted operation of a manufacture there is a reserve stock of cutting tools created. For this purpose there are plans of using instruments in accordance with technological processes of all parts machined in the shop during the nearest periods (usually during a shift, a day, a month and three months), the instruments are divided into groups according to cutting tool life and the greatest usage. The reserve stock is defined by means of table data of minimum operating fund (Tab. 16.2).

Table 16.2

Minimum operating fund of cutting tools, pieces

Tools	Time allowance for restoration	Cutting edge life	Quantity of simultaneously used tools of the given range, piece					
	hrs.		*1*	*2*	*3*	*4*	*5*	*6*
1	2	3	3	4	5	6	7	8
Cutters, drills, reamers, core drills, boring bits, countersink reamers, cutting taps, end and slot mills	4.0	1.0	10	10	28	36	45	54
		1.5	8	15	23	29	36	43
		2.0	6	11	17	22	27	32
		4.0	5	9	14	18	22	27
		8.0	4	7	11	14	18	22
Shaped cutters, step drills, complex core drills, assembled reamers, cylindrical mills	8.0	1.5	14	27	40	50	63	---
		2.0	10	19	28	36	45	---
		4.0	6	11	17	22	27	---
		8.0 and more	4	7	11	14	---	---
Boring blocks, inserted- blade milling cutters with diameter up to 300 mm, boring heads	12.0	2.0	14	27	40	---	---	----
		4.0	8	15	23	---	---	---
		8.0 and more	5	9	14	---	---	---

The most often used small tools are stored on shelves of the racks at height from waist to shoulders according to their types and size increasing, tool sets are created (for example, cutting taps and drills of this size). Light tools, which are rarely used, are stored on racks at height more than 2.5 m, heavy attachments and tools – on the lower shelves. All cells and boxes are marked, there is an instrument registration book; the required tools for technological processes are ordered and bought in advance. The specific area for a tool storage room depends on the type of manufacture:

1. for single-piece production – 0.7–1.2 m^2/machine tool;
2. for small-scale production – 0.6–1.0 m^2/machine tool;
3. for medium-size production – 0.5–0.8 m^2/machine tool;
4. for large-scale production – 0.4–0.6 m^2/machine tool;
5. for mass production – 0.3–0.4 m^2/machine tool.

The large specific area is applied when storing not only tools but also attachments in a tool storage room. Measuring tools and gages are often stored in a tool storage room, for this purpose the specific area 0.1 m^2/machine tool is used.

In tool storage rooms in the area of storing and kitting tools and technological documents there are also store rooms for abrasive tools and benchwork and assembly tools. A store rooms for abrasive tools is created if there are grinding, tool-grinding or buffing machines in the shop. The store room area is calculated in accordance with the specific area 0.4–0.5 m^2 per one of the enumerated machine tools for flow-line production and 0.5–0.8 m^2 for non-line production.

There is one storekeeper for 30–40 units of equipment; he is responsible for delivering some abrasive tool to machine tools and the worn abrasive tool to the store room. In a store room abrasive tools should be stored in vertical position and should be preliminary tested for abruption.

The amount of resharpenings of the tool m is determined by dividing length of working part L into value of admissible closing for one resharpening ℓ ($m = L / \ell$), and cutting tool work time (an operation resource) $\tau = m \times T$, where T – is cutting tool life.

Special attention is given to availability of to-size cutting tools (drills, core drills, reamers, cutting taps and thread cutting dies and etc.) of the necessary spectrum. The absence at least of one demanded size will result in paralyzing the manufacture. Except the cutting tools, it is necessary to have a considerable amount of various production tooling and attachments available: adapter sleeves for end tools (for drilling machines and lathes) with cone shanks (with Morse cones №1 to №2, №2-3, №3-4, №4-5, №6-7, from №1 to №3 and etc.), adapter sleeves for milling machine tools, pull studs for fixing milling cutters, collet chuck attachments with a set of collets, expandable holding devices (self-centering mandrels) for holes with various diameters, self-centering turning chucks and independent 4 jaw chucks and etc.

When delivering tools to the process equipment by transportation workers, the quantity of tools can be calculated in accordance with the formula $C_{t\,w} = 0.06 \times C_{ac}$, where C_{ac} – an acceptable quantity of served machine tools; and the number of bogies for delivery $C_b = k_t \times C_{ac}$, where k_t – the factor considering the type of equipment (for lathes $k_t = 0.4$; for multi-operation machines with a storage device: up to 20 tools $k_t = 0.12$; up to 50 tools $k_t = 0.6$; over 50 tools $k_t = 1.2$).

Disassembling the worked-out tools is done by the toolmaker replacing dull tool plates with mechanical fixing. The disassembled tools are sorted by degree of suitability and transmitted to their destination (for inspecting, restoring, reconditioning and etc.). The number of toolmakers for disassembling tools at engineering design is 40 % from the quantity of toolmakers for adjusting tools, and the number of toolmakers for kitting tools is 50 % from the quantity of toolmakers for adjusting tools.

The area necessary for disassembling tools, for stores foremen is calculated according to their quantity in a shift, and according to the additional area occupied by a stores foreman (5 $м^2$) and a toolmaker (7 $м^2$).

The area for storing cutting tools is $F_t = C_{ac} \times K_r \times f_t$, where $K_r = 0.5$ – the factor considering storage of tools on high-level racks; $f_t = 0.7–2.2$ $м^2$ – the area necessary for storing tools for one machine tool (it is selected according to seriality of production and equipment type [2]). The total area occupied by the section providing machine tools with instruments is the sum of the areas for storing and kitting tools and technological documents storage as well as for disassembling tools.

The area of a store room for repair-assembly tools is determined by calculation 0.15 $м^2$ for one assembly fitter of the shop floor production. The tools for clinching, assembling threaded junctions, press fitting, rolling, drillings and thread cutting, filing and conditioning, shaving and other operations are stored here.

Except a tool storage room, the tool management service is introduced in the shop by a tool-grinding department which is located near the wall close to sites of lathes and drill machines. From the main room the tool-grinding department is separated by a partition to reduce the noise and abrasive dust, there is a powerful exhaust ventilation system. In the tool-grinding department abrasive machine tools with large and fine grains, and with green wheels for sharpening cemented carbide tools, and with white (red) – for sharpening high speed steel cutting tools, other cutting and constructional steels are mounted. A tool grinder or a foreman or some worker (combined duties) is responsible for wheel condition. Wheels are periodically corrected with crushers, elbow rest position is regulated; wheels after significant wear are changed with the new ones.

The department of cutting tool restoration is organized for the centralized repeated sharpening and maintenance of the cutting tools used in the shop. If there are 150 – 300 machine tools in the shop, a restoration department is organized to recondition cutting tools; if there are more than 300 machine tools, two-three restoration departments can be organized. If there are less than 150 machine tools in the shop, restoration of the cutting tools is done in the factory tool shop.

A number of multiple-purpose tool sharpeners in the restoration department (percentage from the quantity of served machine tools) are assumed 3–5 % for flow-line production and 3–4 % for non-line production . Greater percentage of sharpeners is taken when the quantity of served machine tools is up to 200, less percentage – when the quantity of served machine tools is above 500.

In departments with finishing edge cutting machining the sharpeners are equipped with diamond and abrasive cubic boron nitride wheels for finishing sharpening of cutting tools edges. Complex tools (mills, broach tools, reamers, etc.) are usually sharpened centrally in a factory tool-grinding division by using special attachments.

Except a tool shop, divisions for attachment restoration and repair are organized in big shops of the large factories. These divisions are equipped with necessary machine tools and equipment: multiple-purpose tool-grinding, special tool-grinding (for example: for sharpening drills, cold cutting saws/slitting saws and etc.), flat surface and cylindrical grinders, internal bore grinder, multiple-purpose turning, milling and drilling machines; hand power and hydraulic presses, electrical discharge machines for tool marking, workbenches with jaw vises, heating furnaces for press fitting, etc.

To adjust tools with adjustable attachments there are sites organized. They are equipped with indicator devises, toolmaker microscopes, projectors and etc. The specific area for reconditioning sites is usually calculated as 10 m^2 per one machine tool.

The size can be quickly checked with an indicating grinding gage. This gage indicates the size of the work while the machine is running.

16.4. Repair and maintenance service

The repair and maintenance service is intended for serving the equipment of main and auxiliary production, lifting and transporting equipment, chip removal system, the centralized delivery of cutting fluid, process air supply systems, electric power supply systems, electronic systems, furnaces and etc.

In the heart of repair and maintenance service lies scheduled maintenance. For this purpose the master mechanic of the shop makes an inspection schedule and planned equipment maintenance. Each machine tool has a record card which contains the date when equipment was manufactured, when it was delivered to the shop, its condition, a schedule of planned maintenance and repair according to the category of the equipment repair complexity (for example, the machine tool 1K62 has the 11th category). For each group the own structure and periods are provided (for example, I – I – I – I – M– I – ….– I – – I – MM – I–…– – I – GM – I – I, where I is visual inspection, M – maintenance, MM – medium maintenance, GM – general maintenance). A machine tool record card contains all visual inspections and maintenance, types of breakages, the name of parts for preventive and emergency replacement.

During visual inspection adjustment, lubrication, replacement of worn parts take place if it does not demand to stop the equipment for a long time. If replacement is impossible during visual inspection, a corresponding record to make a change at the nearest reconditioning is done in the record card of the machine tool. During corrective (minor repairs) or medium maintenance the machine tool is put out from production for some days, therefore it should be co-ordinated with the foreman. During general maintenance the machine tool is put out from production for a long time and even it can be taken to the mechanical repair department (for grinding slides, modernization and etc.).

The integrated standard time for repair operations of metal-cutting equipment (in accordance with the repair type) are recommended for applying at the enterprises irrespective of their departmental affiliation and intended for labour rate setting of the workers engaged in reconditioning of cutting machines due to piece rate wage plan, and standardized task setting [6].

The integrated standard time can be used when calculating complex norms for introducing the team form of labour organization and labour stimulation. Below you can find the standard content of operations in accordance with the repair type.

General maintenance: accuracy test before disassembling; wear sensing measurements of rubbing surfaces before reconditioning base parts; a complete dismantle of the machine tool and all its assembly units, washing, wiping and visual inspection; fault detection of the whole machine tool; replacement and restoration of worn-out parts; reconditioning of lubricating systems, cutting fluid and hydraulic systems; grinding or scraping all guide planes; reconditioning or substituting guard bodies fixed according to the safety instructions and devices for protecting the machined surfaces of the machine tool from chip and abrasive dust; assembly of all assembly units of the machine tool, verification of units interaction. It also includes puttying and painting all internal and external surfaces in accordance with technical specifications; running at idle at all speed rates and feeds; testing smoothness of operation of a kinematic scheme and its load trial.

Medium maintenance: partial dismantling of the machine tool, washing, wiping and visual inspection of parts of the disassembled assembly units, cleaning not disassembled units and parts from mud, updating a preliminary failure repair sheet; replacement or restoration of worn-out assembly units and parts; inspecting and clearing new assembly units and parts left in the machine tool; reconditioning of lubrication systems, cutting fluid and hydraulics systems; supervisory scraping or grinding of guide surfaces which are in need of repair if their wear-and-tear exceeds the permissible limit; reconditioning or substituting the guard bodies fixed according to the safety instructions and devices for protecting the machined surfaces of the machine tool from chip and abrasive dust; assembly of repaired assembly units; interaction verification of all units of the machine tool. It also includes painting of external nonfunctional surfaces of the machine tool; running at idle at all speed rates and feeds; testing smoothness of operation of a kinematic scheme and its load trial.

Corrective maintenance: partial dismantling of the machine tool, constituent part dismantling of two-three assembly units prone to the greatest wear-and-tear and dirtying; opening covers and manholes for internal inspection, washing and scrubbing other assembly units; cleaning the whole machine tool; blowing with compressed air; visual inspection, cleaning parts of disassembled assembly units, base planes and slides; making or updating a preliminary failure repair sheet and detecting parts demanding replacement or repair at the nearest planned maintenance with a record in the preliminary failure repair sheet; verification of functionality and adjustment of the machine units; replacement of worn-out parts; adding friction plates; scraping off friction clutches cones; adjusting friction clutches and brakes; conditioning of scratches, score marks, handling marks, nicks-and-burrs of the machine tool wear surfaces; adjusting of hydraulic system elements and lubricating system repair, oil replacement; inspection and repair of cooling system; eliminating liquid leakage and afterdribble; small repair of pumps and mountings; repair or replacement of the guard bodies fixed according to the safety instructions and devices for protecting the machined surfaces of the machine tool from chip and abrasive dust; testing the machine tool accuracy.

Time standard development is based on time typical technological processes of repairing machine tools, mechanical engineering time standards for mechanical works to repair equipment, stop-watch reading data taken by regulatory research organizations in enterprises; results of analyzing labour organization in the enterprises.

Labour input of all types of repair work is defined by repair complexity of operations. For mechanical equipment labour input of one unit of repair complexity (R) is assumed equal to 1/11 of labour input for repairing the screw lather 1К62 taken as a measurement standard and related to the 11th category of complexity, i.e. for the machine tool 1К62 R = 11. For the mechanical part of this machine tool labour input of general maintenance is assumed equal 50 hours, for the electrical part – 12.5 hours.

The calculation of machine tools quantity of the repair service, quantity of machine tool operators and repair men is carried out in the same way as for mechanical divisions and shops, proceeding from the common labour input defined by time standard for each unit of repair complexity (R=1).

Labour input of annual repair size of all machine tools in the shop is calculated by formula

$$T_r = \Sigma(R_i \times q_{r\,i}),$$

where: R_i – the repair complexity category of a machine tool; $q_{r\,i}$ – the common labour input of one repair unit of the corresponding complexity category.

At the factories with labour force up to 600 people there is a centralized form of serving when a team of repair men come to the shop on call or according to the schedule of preventive maintenance inspections and repairs.

In large factories the mixed form of serving is applied when visual inspections and small repairs are performed by a shop team, and general and medium maintenance – by a factory team. In medium and large departments (over 100 people) there are 2–4 repair men in each shift for corrective maintenance of mechanical parts of the machine tool and 1–2 electricians. When designing a repair system the calculation of repair men and electricians quantity is done due to the labour input of corresponding operations. If there are NC machine tools, service of control cabinet is performed by the electronics engineer.

In medium and large shops the area for the equipment of maintenance service is calculated as 22–28 m^2 per one machine tool. The machine tools quantity of repair service usually makes 2 % from the quantity of production equipment. The equipment of repair base is hand-operated and hydraulic presses; arc-welding transformers; electrical drills; grinding machines; metal sawing machines; grinders with a flexible drive shaft; abrasive machines;

drilling, turning and multiple-purpose milling machine tools and etc. To work on this equipment there is a staff of all-round craftsmen. The level of equipment use does not usually exceed 0.5–0.7.

Electricians are usually placed in a separate location and have their own equipment (attachments for electrical motor winding, removers, workbenches with jaws, presses and etc.). For storing repaired electric motors there is a storage room or a ground with the area 10–25 m^2 provided.

For general maintenance of the equipment and its modernization at the factory the mechanical-repair shop (MRS) is created. It is equipped with necessary machine tools (lathes, press drills, milling, planning, horizontal boring-and-turning mills, surface and cylindrical grinders, internal bore grinders, piano-type surface grinding machines, vertical turret lathes, guillotines for cutting metal sheets and bars and etc.). In the MRS there is an advanced welding division (site) for cutting metal sheets and slabs and welding case-shaped parts, as well as a big store room of materials (sheets and bars).

A ***chip conveyor system*** is created *for removing and processing chip*. If there are less than 0.3 tons of chip from 1 m^2 of the shop in a year, it is collected into a container; if there are more than 0.3 t/m^2, the chip drop on the linear conveyor which is installed under machine tools at a depth of 600–700 mm, and then the chip is transferred to the container at the end of the span or shop. In large departments the chip is transferred by the linear conveyor to the main conveyor located in the tunnel at a depth of three meters, and then – to the container for processing. Belt-type conveyors, drag-type conveyors, conveyor worms, conveyors with a magnetic field are applied.

To estimate the expected amount of chips the weight of the annual programme of all parts is defined, and then 15 % of this value is taken for series manufacture and 50 % – for small-size production. In aircraft building the weight of the chip can make up to 90 % of the weight of the part since moulding and press forming can be disallowed.

To be removed well the chip should not be longer than 200 mm, and the diameter of a spiral turn – not more than 25 mm. To form chips into a convenient shape (tight spirals) chip breakers are applied; chip control grooves are sharpened or stamped on face of tips, cutting fluid or air is pumped under high pressure into the area of chip formation, intermittent feed and other techniques are used. Too small (broken) chips are got into attachments and removed badly. The long chips are dangerous for the worker, they are badly removed, bird-nested on rotating parts of the machine tool and attachments, take too much room in the container.

As for single-piece and a small-scale production it is possible to machine parts from different materials, therefore it is not allowed to mix heterogeneous chip when gathering them into containers. Steel chip, iron chip (but it is allowed to mix in small amounts with steel), aluminium, copper, titanic, stainless steel, refractory (heat-resistance) alloys and etc. are gathered separately. When chips of different types get into one container, the container contents are dug in, and the foreman or worker responsible for mixing get a fine.

Before processing nonmagnetic chips undergo a magnetic separation in order to remove the fragments of the cutting tool if it was broken. Further the chip is broken up, degreased in special jet washers with hot water or alkaline solutions; the moisture is deleted in a centrifugal machine, preforms of 5 – 8 kg are pressed and sent for melting. To be better broken up the chip can be additionally crisped with liquid nitrogen or frozen carbon dioxide, sometimes it is even hardened/quenched (for needs of metal powder industry).

The coolant supply system is intended for preparing and supplying cutting fluid to work positions with the pipeline (central coolant supply). At single-piece and small-scale production cutting fluid is filled in a capacity located under the tray of the machine tool and delivered to the working area with the pump of the machine tool.

If there is central coolant supply, the site area for preparing cutting fluid for 50 – 400 machine tools occupies 40–120 m^2. This site is located near the external wall in order to simplify the installation of ventilation. Cutting fluid concentrate is mixed up in the necessary proportion with water or oil, and then it is cooled and delivered with a pump station to the pipeline. On a machine tool the outspent cutting fluid flows down into the tank and then the gravity flow arrives at the cutting fluid site where it is filtered from the fragments of chips by filters and in a centrifugal machine, cutting fluid concentrate is added, it is cooled and pumped into the pipeline.

To prevent bacteria from breeding in cutting fluid antibiotics are added in it or the process of aeration (oxygen saturation) takes place, since the majority of bacteria are anaerobiotic and perish from oxygen. In a certain amount of cycles cutting fluid is completely replaced.

Cutting fluid should take away heat well from cutting edges, facilitate chip formation, diminish the friction coefficient of the chip with the cutting face, create a protective film on the surface of the tool for reducing oxidation and adhesive fatigue wear, include rust inhibitors for preventing corrosion of the machine tool. Cutting fluid is also used for curling chips and removing them from the cutting area.

Some types of cutting fluid are hazardous to human health: it can cause allergies, skin irritation, eye irritation, respiratory passage irritation and even cause cancer; but they are applied because of high efficiency (for example, carbon tetrachloride CCl_4, sulfofrezol and etc.). To work with such cutting fluid extreme caution is required (sometimes even a gas mask and rubber gloves are used).

Besides water-mix cutting fluid different oils with additive compounds are widely applied for protective films on tool working surfaces. Double- and triple-action oils are applied, i.e. it is possible to use them to lubricate the machine tool parts, in hydraulic systems of the machine tool and its attachments.

Except cutting fluids, lubricant-cooling agents can be applied: liquid nitrogen, air, surface-active agents in the form of paste (albany grease) coated on tool working surfaces, and etc. In certain cases the application of cutting fluids is not allowed (for example, when machining titanium alloys because of chip contamination and impossibility of its further processing, when machining cast iron – because of dirtying a machine tool and low efficiency, etc.). In such cases the compressed air brought to the cutting zone is usually applied.

To store cutting fluids and its concentrates the area is allocated in accordance with 0.1 m^2 per a machine tool. This area is usually located in a storehouse for combustibles and lubricants or in a storehouse for blanks (see section "Storehouse service").

The ***electrical supply system*** is intended for voltage reduction of the brought electric power and its supply to work positions. To reduce losses while transmitting electric power, voltage on power transmission lines is increased to 110 кВ (less current strength for transmitting the same power $P=U\times I$ is required). In the enterprise (in the central electric power substation) a series of step down transformers 110/35 kV and 35/10 kV is located outdoors, and transformers 10/6 kV and 6/0.4 kV are located in the shop (indoors).

Three-phase voltage 380 V (0.4 kV) is supplied to the equipment with the conductor cables laid on the pipes along walls and under the floor. Production floor of 5000 m^2 requires one shop substation occupying up to 50 m^2. The distance between substations is usually 100–300 m. For operative voltage disconnection power cabinets (PC) with knife switches and fuses are installed not further than 25 m from the equipment. For each group of equipments in a power cabinet (three phases and a fuse on each phase) it is pointed what machine tools are connected to this group.

The shop power engineer has a consumers' sheet with the rated power for each machine tool and secondary (auxiliary) equipment. On the base of total rated power the cross sectional area of electric cables is calculated and the required capacity of capacitors for improving $\cos \varphi$ of the power system is defined. Electricians also have a power *supply scheme* for machine tools and other consumers (ventilators, industrial air conditioners, lighters and etc.).

To charge accumulators (replacement battery) of electrocars there is an accumulator station in the shop. This station has good ventilation since there are electrolyte vapors.

To supply attachments with compressed air ***a compressor station*** is located in the shop. The rated power of the station is calculated in accordance with the compressed air consumption by consumers. In addition, compressed to 0.5–0.6 MPa air is drained in order to avoid condensed vapor in the system. The area of a compressor station makes 1–6% from the floor space.

To create good atmosphere in the shop areas there is ***a ventilation system*** served by the repair and maintenance service.

16.5. Quality inspection service

The functions of the quality inspection service are:

1. storing information about fabricated articles;
2. acceptance and functional inspection of quality with conformance inspection to drawings and specifications;
3. providing information on the results of quality inspection;
4. providing timely isolation of faulty production;
5. adjusting inspection-measuring devices and machines.

Quality inspection service consists of:

1. quality control department (QCD) of the factory;
2. central measuring laboratory (CML), or central factory laboratory (CFL);
3. monitoring and checkout points subordinated to the central measuring laboratory and located in workshops;
4. shop checkout points and testing floors.

The quality control department of the factory is responsible for all aspects of supervisory services: it makes a work schedule for all subdivisions of the inspection service; performs management and control; coordinates activities and methods with the heads of services, shops and departments; makes reports on inspection results for company's management team (per shift, per day, per week, per month, per quarter, per six months, per year); closely cooperates with the production department of the factory.

The central factory laboratory of the factory develops inspection schemes and plans of measuring tools, performs the most difficult inspections, makes complex measuring operations (composition control of materials, their structure and hardness, control of physical and mechanical characteristics of used materials, control of complex items and random total quality control and etc.).

Monitoring and checkout points perform sampling or total inspection of produced articles and incoming blanks and semi-finished products, inspection of articles after crucial processes, checks work of shop inspectors by reverifications, make conclusions about operational efficiency of lines, sites and shops in whole.

Shop inspectors measure and monitor articles after each operation. At mass production total inspection is carried out, in other cases the percentage of inspected articles is defined by the significance of the process and occurrence probability of defective products (it depends on required accuracy, equipment accuracy condition, qualification of workers) and it can make 5 %, 10 % and 25 %. Inspection with use of bulky and heavy measuring instruments (toolmaker's microscopes, twisted-spring micrometers on stands, profile recorders, devices for measuring rotating accuracy and etc.) is performed at stationary check points, and in other cases – casual inspection is used.

If there is a defective article detected, the inspector marks the defective unit with paint, makes a record about it in the inspection record book specifying the worker’s surname and takes measures for isolating the faulty item. If the rejection rate detected by sampling inspection is high (it is defined by operation significance, article cost and it usually makes not more than 3 %), all parts are subject to total inspection and the foreman is immediately informed about it.

When assigning tools and methods of measurement it is necessary to select them correctly. The procedural error should not exceed 10 % of the testing parameter tolerance. In insignificant cases when using a direct gauging technique the division value (graduation) of the measuring tool should be 5–10 times less than the testing parameter tolerance (as a rule, the error of a measuring tool is ± of the division value).

To reduce defective items it is better to apply in-process gauging technique which allows to perform measurements in the process of machining (for example, when grinding a shaft it is possible to measure the received diameter by means of a sensor which comes into contact with the machined surface). Using passive control technique gauging or measuring is performed after the operation and its results can be taken into account only when manufacturing the next part.

To inspect articles with complex shape the measuring machines are used. They are located in temperature-controlled rooms with restricted access. Meanwhile the temperature is withstood accurate within the several hundredth fractions of degree.

After being assembled the article is usually tested or even given trial runs, for this purpose there is a special testing ground created in the shop. If possible, adjusting is also carried out there.

16.6. Labour safety and consumer services

In the labour safety service there are several ***subsystems***:

1. ***Providing safe work of the personnel***:
   - Fire safety.
   - Safe equipment use and maintenance.
   - Protection against mechanical devices.
   - Protection against the chip and cutting liquid.
   - Electrical safety.

2. ***Providing sanitary working conditions***:
   - Room cleanness control.
   - Air quality control.
   - Protection against noise.
   - Protection against vibration.
   - Illumination control.
   - Industrial aesthetics.

3. ***Serving the personnel***:
   - Public catering service.
   - Health service.
   - Consumer service.

According to the types of serving and arranging the factory the consumer service is divided into 3 groups:

1. local – smoking rooms, rest rooms, drinking facilities (located not further than 90 m from workplaces);
2. shop and intershop – cloakrooms, shower rooms (located not further than 400 m);
3. factory-wide – dry-cleaners, laundries, shoe repair shops and etc. (located not further than 800 m, but for big factories – several kilometers).

Applying automatic fire detection systems is one of the basic conditions for providing fire safety since it allows warning the duty personnel about a fire and its area. For this purpose there are smoke detectors placed in the locations (one detector for 60 – 70 m^2). Emergency exits from rooms should be located at several places not near to each other. The width of evacuation route should be not less than 1 m and the width of doors for evacuation route – not less than 0.8 m, and doors should open out.

To provide air environment cleanness it is necessary to equip grinding machines, polishing machines and sharpeners with ventilated casing and local exhaust ventilating devices.

Welfare spaces are located more often in a two-floor (or multi-floor) annexe to the manufacturing building. On the ground floor there are auxiliary shop subdivisions and water closets; on the upper floors there are cloakrooms and shower rooms, office facilities and rooms for psychological relieving of the personnel.

The maximum comfort for manufacturing buildings with about 2 thousand employees working is brought by arranging a complex of consumer services in a separate building linked to manufacturing facilities with passages.

Smoking rooms are located not further than 100 m from the most remote workplace. These rooms should have benches and ash bins in accordance with the approved plan of the interior for welfare buildings.

Walls, doors and the equipment of water closets should be coated with such materials which do not change the colour when the mud is washed off from them and from which all water flows down. It is obligatory to fix taps with hot and cold water to wash floors, walls and equipment. Drinking facilities are placed on production floor spaces at the most convenient places to be used.

In standard projects of welfare annexes each hall of the cloakroom is divided into cells equipped with necessary sanitary-engineering installations (wash basins, showers). A group of cupboards are separated from passageways with sliding doors thanks to which it is possible to use the cloakroom for serving different number of men and women. Two isolated light passageways divide the flows of workers going to and from work. The width between cupboards is 2 m that gives a possibility to put benches for all workers using the cloakroom to change clothes. In the cells double cupboards are placed for keeping street and home clothes and single cupboards for keeping working clothes. The size of double cupboards is 350 × 500 × 1800 mm, single cupboard – 250 × 500 × 1800 mm. In the annexes there are shower cabins of closed type installed with places for changing clothes. The quantity of washing taps is one for ten persons, irrespective of workers' speciality and production processes they carried out. In cloakrooms there are special facilities provided for cleaning with cold and hot water. It is recommended to fix mirrors, shoe cleaners, hair dryers in the cloakroom.

For automatic machines, kiosks and stalls the service-area radius is equal to 50–90 m and they are usually installed in close vicinity to manufacturing floors or in some cases on manufacturing floors (if it meets the hygienic requirements). The necessary area for automatic machines is 0.2 m^2; for kiosks – 3–4 m^2. Cafeterias and canteens serve workers within a radius of 200 – 400 m, and they are organized in welfare locations near big manufacturing buildings. Cafeterias demand the area of 0.05 m^2, and canteens – 0.6 m^2 for serving one person.

If more than 300 persons work in the shop, there is a feldsher's post organized where preventive examinations are taken, injections are given and etc. At medium and large factories there is a health centre occupying the area of 50 m^2 and containing several rooms (a waiting room, doctor’s or medical assistant’s consulting room, a treatment room, an isolation ward). At large factories a preventorium can be constructed near the factory.

16.7. Management and production planning services

The given section is based on the textbook “Machinery production design” by Petkau E.P, Matveev V.S. and Zhuravlyov V.A.

The management and production planning services (MPPS) has an important role in production output and financial viability of the enterprise. Even having modern equipment and advanced technologies management system failures will inevitably cause idle times, deterioration in quality of output products, earnings dilution and, in cases when this service is extremely low efficient, it can cause bankruptcy of the enterprise. The more complex the equipment is, the higher its cost and automation, the higher requirements for the performance quality of the management and production planning services since its idle time costs much more than idle time of usual general-purpose equipment. In connection with great significance of the management and production planning services the development of the manufacturing execution system and the enterprise management system has become an independent part of the project.

Control objects at the factory are all organizational-technical systems (services). The main services are: technological, tool management and production planning, inspection and quality assurance of products, labour safety, equipment maintenance, storehouse and transport, financial and economic, economic analysis and human recourses, logistical support and production realization.

The management system of the shop is similar to the management system of the factory, especially when it is highly economic independent and is a small-scale manufacture, when there are decentralized auxiliary services. The management system of the shop is a component of the factory management system which solves all questions of calendar and economic planning on a factory scale at higher level. The basis for production scheduling is complete information about conditions and possibilities of manufacture support and finished goods realization (product portfolio).

The main purpose of the management system in the machine-assembling shop is to provide balancing production process of the required volume and with least costs. To achieve the given purpose the management system of the shop should solve the following basic tasks:

1. Day-to-day production planning.
2. Preparing process flow and planning documentation.
3. Preparing equipment, machining attachments, cutting and measuring tools.
4. Providing the manufacture with necessary blanks, materials and component parts.
5. Training the personnel.
6. Providing safe working conditions in the shop.
7. Monitoring and effective production control (continuous control of the condition of the manufacturing process and influence on it in the case of an emerged deviation).
8. Staff incentive.
9. Technical maintenance, service, repair of the equipment and attachments within the required volumes.
10. Accounting and economic analysis of manufacturing and economic activities of the shop.

The structure of the management system should be simpler when possible, has fewer levels and interconnections between divisions since the unnecessary levels reduce efficiency of the senior management. It is not recommended to create too large divisions since it becomes more complicated to manage them; it is more difficult to find sufficiently qualified managers. It is necessary to adhere to the recommended spans of management. One manager should control not more than 5 – 8 managers of the lower management levels. The right number of a production team should be from 5 to 15 persons, subordinate to the foreman – from 15 to 30 persons, subordinate to the senior foreman (the shopfloor manager) – from 40 to 60 persons.

An example diagram of the management system of the machine assembly department can look as follows (Fig. 16.7).

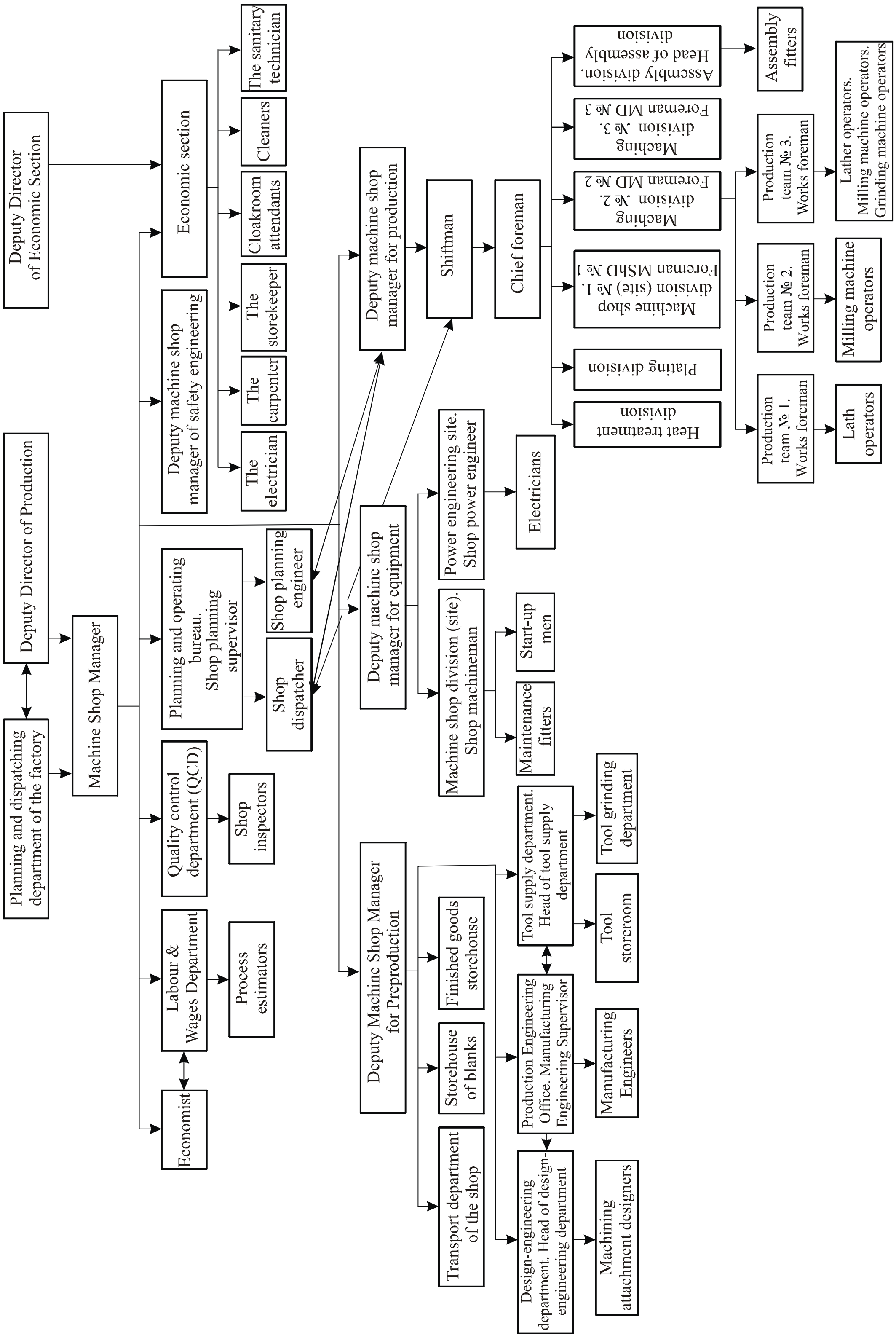


Fig. 16.7. The management system diagram of the machine assembly department [5]

When designing a management system it is necessary to ensure the correct distribution of functions between divisions, responsibilities, rights and personal responsibility of the managers of these divisions. The functions of the divisions should be clearly formulated in the guideline for each division, and the rights, duties and responsibility of the manager – in the duty regulations.

The management system should ensure unity of direction, i.e. each worker should submit directly only to one manager who he receives tasks from, reports back to and who evaluates the quality of his work.

It is very important to define specific indexes according to which work of each manager, worker and labour (production) collective is evaluated. Such index should stimulate economic efficiency of work and the end result of the collective work (of a team, division, department, shop) and each worker individually. For example, it can be the quantity of machined parts, accepted assembly units, etc.

Day-to-day production planning (DPP) is one of the main tasks of the management system of machine-assembly shop production. The key function of DPP is fixed-schedule supply of work positions with objects and instruments of labour. More than 50 % of all losses of working hours are caused by untimely supply of work positions with blanks, tools, necessary attachments and containers.

To provide a production rhythm and output within the required volume and with the least costs the *rapid response (dispatching) system* has to perform the following functions:

- To exercise continuous control of carrying out the production process;
- To take operative decisions and to influence the production process in case of deviations;
- To analyze the reasons of deviations especially those which are repeated and to control both taking and accomplishing measures of the short-term and strategic plan of actions aimed at avoiding such situations in future.

In the factory there is dispatchers' service created who watch over plan performance, availability of blanks, materials and backlogs, rejection rate, amount of unfinished goods, prospects for schedule performance in the nearest days, weeks and etc. Nowadays at the advanced enterprises the necessary data on current production in the shops and sites are computerized and continuously or periodically updated. The dispatcher has a possibility to receive the necessary information from the computer network at any moment and take measures for improving the situation (to organize manufacture of critical parts or to perform some operations additionally in other shops or sites, to make an order for purchasing blanks, materials, tools and etc.).

Regulations of the dispatching control contain the exact time of operation, the responsible officer, the contents of operations (action); participants, who receive the information transmitted. For example, from 8.19 till 8.25 the senior dispatcher or, in his absence, the shift supervisor conducts by interphone communication the dispatching report on readiness (provision) of the shift. All shift foremen participate in it. The information of the report results is forwarded to the deputy shop foreman for production who analyzes the revealed deviations and takes the corresponding decisions.

From the production planning department and the planning and dispatching department of the factory annual and monthly production plans along with economic indexes are passed to the planning and dispatching office of the shop. These plans are initial ones to make monthly tasks for divisions and each brigade. The monthly task to a brigade is given in the form of a duty bulletin in which all range of parts with their prices and salaries are specified.

The division planners, who are in the planning and dispatching office of the shop, receive a monthly task for their division. Taking into account the monthly schedule of machining particular parts, division planners draw up the tasks for their division for the next "24-hour industrial period" possibilities, state of production, and deficiency forecasts incoming from the data-computing center (DCC).

The blank form of day's production schedule for the department (see Tab. 16.3) first comes in to the production engineering office/technological bureau of the shop. The process engineer of the division checks if there is a process layout (technological process) for machining the required parts. If it is necessary, he makes their correction according to the equipment condition, availability of cutting and measuring tools. If there is not a process layout, the process engineer writes a procedure specification (integrated or detailed depending on serial production), the machine tool model for each operations, the required attachments, cutting and measuring tools must be specified there. In the case when there are no process layouts, the procedure specification is designed beforehand in accordance with the monthly schedule. The process engineer (or process estimator of the production engineering office) calculates the labour input of machining one part for each operation and for all batch workpieces. The batch workpieces is calculated according to the monthly delivery schedule. The machining time of batch workpieces for each operation is calculated.

The calculation results of the designed procedure specification (a new one) are given to the shop planner for scheduling operations of machining batch workpieces. These operations can be performed at different divisions or shops. In accordance with the procedure specification and the schedule of machining batch workpieces the planner gives day's production schedule to the production engineering office.

Table 16.3

Blank form of day's production schedule for the department

<table>
<tr><td colspan="5">TASK
To senior foreman of the site № _______ shop № _______
_____________________within the period from «___» to «___» __________ ______
First name, patronymic, last name date month year</td></tr>
<tr><td>Number of a part (assembly)</td><td>Deadline</td><td>Quantity</td><td>Checkoff</td><td>Note</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="5">In addition the following actions should be carried out in the site :</td></tr>
<tr><td colspan="5">1.</td></tr>
<tr><td colspan="5">2.</td></tr>
<tr><td colspan="5">3.</td></tr>
<tr><td colspan="5">The task has been prepared: the planner ________________ ____________

The technological documentation is checked up,
changes have been done: manufacturing engineering supervisor_______ ___________

The tools, attachments are in running order:
Senior production foreman _______________ ____________

The equipment is in running order: shop machineman ____________ ____________
• shop power engineer ____________ ____________

Head of planning and operating bureau ______________ ___________
Senior foreman _________________ ___________</td></tr>
</table>

After the process engineer the blank form of day's production schedule for the division comes in to the tool storage room in order to control tool availability for each position, to prepare tools and necessary attachments.

Then the task is approved by the deputy shop foreman for equipment. The deputy shop foreman or the mechanic himself and the shop power engineer make analyses of shift tasks from the point of view of operative equipment availability and, if necessary, taking operative measures. After that blank form of day's production schedule for the division comes in to the senior foreman of the division.

All the shop services mentioned above confirm the availability of each position with the signatures in the blank of day's production schedule. Together with the deputy shop foreman they take operative decisions about using available backlogs or applying bypassing. In any case, shift-day's production schedule which has not been worked out by providing services should not come to the division.

Requirements for the feedstock (blanks and raw material – metal) and the task of pattern cutting for the blank preparation division are given by the planning engineer of the planning and dispatching office. The senior site foreman gives the shift task to the foreman in the form of a "report" which signed by the foreman at the end of the shift is communicated to the data-computing center for processing and updating data sheets for next day.

Thus, the circuit of day-to-day production scheduling becomes closed. Incoming in the production engineering office schedules of kitting work positions should be made on the base of detailed verifications for actual availability of each position. This work is done by the division planners in collaboration with the gang foreman and the division foreman or on request of the gang foreman or the division foreman.

Practice and experience of advanced mechanical engineering enterprises show that operational planning, production analysis and control should be performed by everybody – from the production manager, shop foreman to the shopfloor foreman and shift dispatcher. But each of them should take actions only at their own level. Consequently, control boundaries and levels should be clearly defined, including timetable. Therefore when developing a project of manufacturing execution system it is advisable to develop a special schedule which would clearly fix a strict time limit: who, at what time and what function they should perform in the production management process.

It is useful to make such schedule for each industrial collective and for the factory as a whole. Even in the process of its development many imperfections (shortcomings) and inexpediency are revealed.

When designing day's production schedules with a strict time limit of their fixed-schedule supply it becomes necessary to accept as an operative scheduling period not calendar, but the so-called "24-hour industrial period" which includes the second shift of the current day and the first shift of the next calendar day. It is explained by the fact that when the second shift works intensively there are various unforeseen deviations from the planned tasks which often have some negative effect at the beginning of the next working day. There is a necessity of corrections and specifications arising. When moving "24-hour industrial period" on one shift, time for designing and providing such planned tasks increases since at the beginning of the first shift it is not spent on corrections and any unexpected situations arising in the second shift. Despite everything, the beginning of the development process of new tasks starts at 11.00 o'clock in the morning, instead of 8.00. During the first three hours the analysis of the last 24-hour period is carried out, the data sheets are processed, and etc.

The big role is assigned to automation of manufacturing execution systems. The great popularity was won by such automated management systems (standards) as ERP (Enterprise Resource Planning) – aimed at planning resources of the factory and MRP II (Manufacturing Resource Planning) – aimed at planning material and production resources [5].

ERP systems are used to solve the following problems:

- elaborating the operative intrashop plan taking into account available reserves and machine tool holding;
- supervisory control of carrying out processes;
- calculating a production plan of manufacturing capacities by various criteria;
- re-calculating the production plan in real time when there are extraordinary situations arising, for example, machine tool breakdowns;
- planning of materials;
- a traffic control of commodity flows (supply, market, organization of transport-storehouse services);
- calculating the actual cost price of manufacturing articles;
- financial management;
- automation of accounting work;
- human resources management, etc.

The ERP system is aimed to decrease production time, to optimize work of marketing services starting from receipt of order till delivery of order to the consumer.

The further development of MRP II and ERP systems took place in CSRP (Customer Synchronized Resource Planning) standard which includes interaction with clients and examines a complete production cycle of an article taking into account all possible requirements of the customer.

Although purchasing the existing projects of management systems demands additional costs and efforts to adapt for use by a particular factory, it has a number of advantages in comparison with developing their own original systems. The most considerable advantages are:

- time for system design is reduced;
- the advanced experience, technologies and management techniques are used;

- the developers provide support of system projects, their renovation and consultations by experienced specialists;
- compatibility of new systems with systems by other similar enterprises of the given branch.

In the international market there is a new service – you can rent an ERP system through the Internet from the supplier server. Rent price is defined by the amount of hours the system was used and the amount of users having access to it.

In general the existing management systems are oriented not to divisions but to factories as a whole, to business processes of the whole corporation. Production management problems within range of shops remain less developed because of their greater individuality.

When developing a computer-integrated manufacturing system (CIMS) it is possible to use services of consultancy firms which develop not only individual projects of management systems on the base of the factory performance findings, but they also ensure their implementation as well as training of managing staff.

In brief, problems of the management and production planning service can be formulated as *planning, accounting and dispatching control*.

When designing a machine shop or site with high economic self-sufficiency auxiliary services, as a rule, are located in the bilding with manufacturing floors. An example of such arrangement is shown in Fig. 16.8. Numbers specify tool-grinding department *1*, sharpeners *2*, areas of blanks *3* and finished parts *4*, push carts *5*, inspection audit room *6*, repair and maintenance department *7* with an electrician and two mechanics, planning and dispatching office *8*, economist and accountant's office *9* with a safe *10*, a process estimator's office *11* with a cupboard *12*.

W – rest room for women; M – rest room for men; 13 – machining attachment designer; 14 and 15 – the foreman and the technologist; 16 – wardrobe; 17 – machine shop manager; 18 – tool storage room; 19 – fire point; 20 – container filled with sand; 21 – storehouse of blanks and finished goods; 22 – storehouse of combustible and lubricant materials.

Shown in Fig. 16.8 the division by amount of the equipment corresponds not to a shop, but a shop division, and it is given here only for education.

Usually a shop consists of 3 – 5 manufacturing divisions. In the same building near to these floors there is a shop supervisory service, a repair service, a tool storage room, a tool-grinding department (sometimes each division has its own one), foremen's office and machine shop manager's office as well. Near to manufacturing floors there are store rooms for banks and materials, store rooms for in-process and finished parts, public accommodations. The production engineering office, process estimators, designers, the planning and operating bureau, etc. are located on the mezzanine floor or in a two- or three- floor buiding adjoining the industrial building.

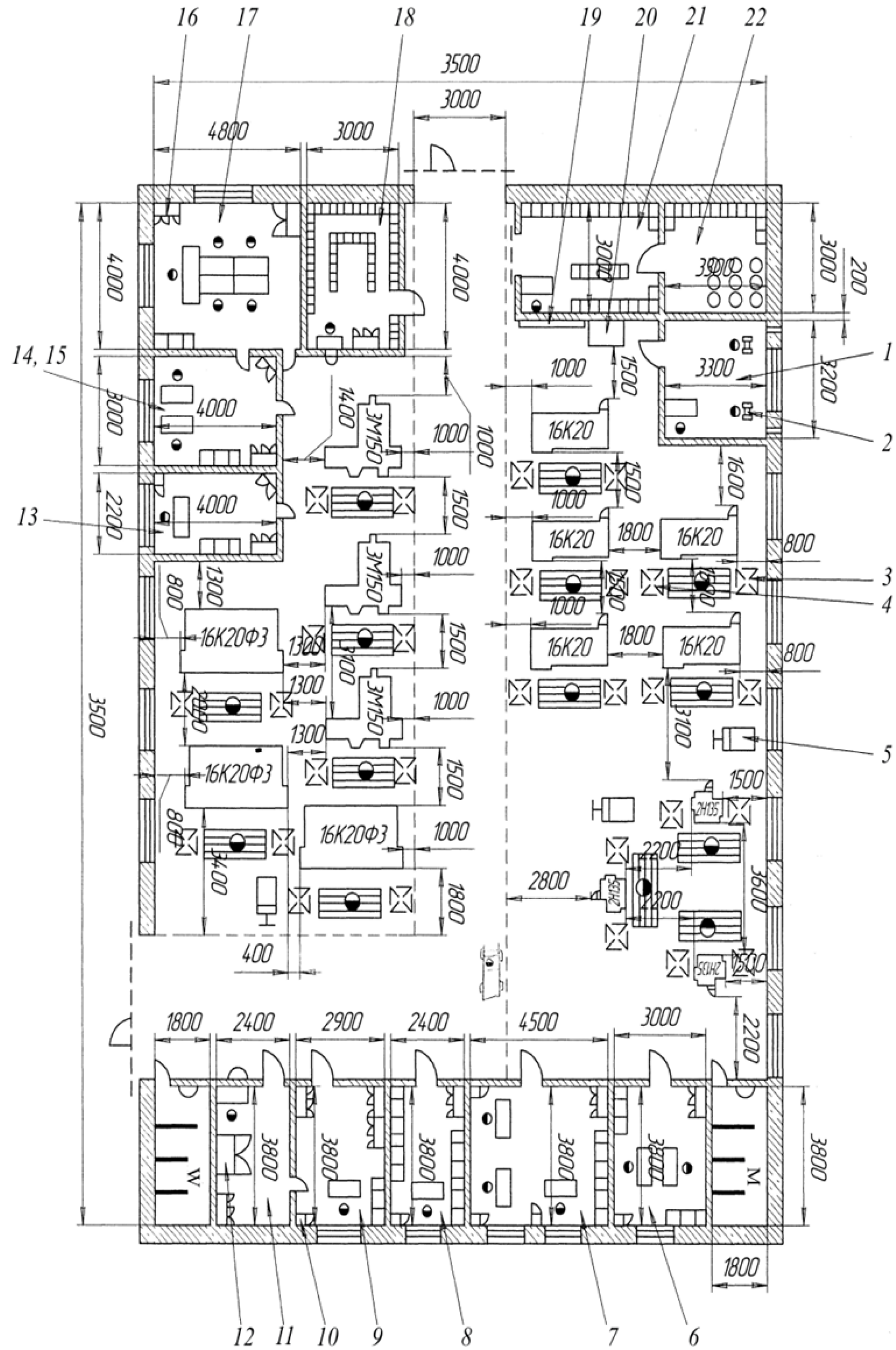


Fig. 16.8. An example of a site layout with high economic self-sufficiency

17. SHOP LAYOUT AND DESIGN DECISIONS

When designing a new shop it is very important to choose the right type of an industrial building, its arrangement, dimensions in the plan. When reconstructing and modernizing manufacture it is essential to use available industrial buildings in the optimal way for locating new divisions and shops. The cost of industrial buildings in mechanical engineering is rather high and covers 30 – 40 % of the cost of fixed capital assets of an enterprise [1].

Space-planning decisions of industrial buildings can be various. For mechanical assembly production shops there are one-storied and many-storied buildings with roof monitors that can provide light and ventilation (raised structures on the roof of a building to provide lightning from daylight) and without them, buildings with cranes (equipped with bridge cranes) and buildings without cranes using floor and suspended transport. According to the shape the buildings are usually designed as rectangular ones, however, in some cases they can be L-, U-, or E-shaped. The choice usually depends on the shape and size of a factory area or a tendency to reserve the area for the further extension of shops by means of adding additional spans. U- and E-shaped buildings are applied to reserve areas for extending shopfloors in the future – it takes only to construct a roof between buildings and a facade wall.

At industrial buildings design the frame buildings with unified precast reinforced concrete structural elements are widely adopted. The unified precast elements (UPE) are developed for accelerating and reducing construction design in price. These elements represent a volume part of the building and consist of one or several spans of the same length.

It allows several shops to be placed in one building if it does not contradict working conditions and fire safety requirements. Placing several shops in one building enables to reduce communications and transportation expenses. Cost analysis of creating industrial buildings shows that one-storied buildings having the same production floor space but occupying bigger area than many-storied buildings are cheaper. If the area for building is expensive or limited, it is cheaper to construct many-storied buildings. However, it is impossible to place heavy and high-precision equipment on the second and higher floors. Wider spans and column space of one-storied industrial buildings allow using production floor spaces more effectively since dead-leg areas around the columns are reduced but it raises the price of construction.

Span structural schemes of one-storied industrial buildings are shown in Fig. 17.1.

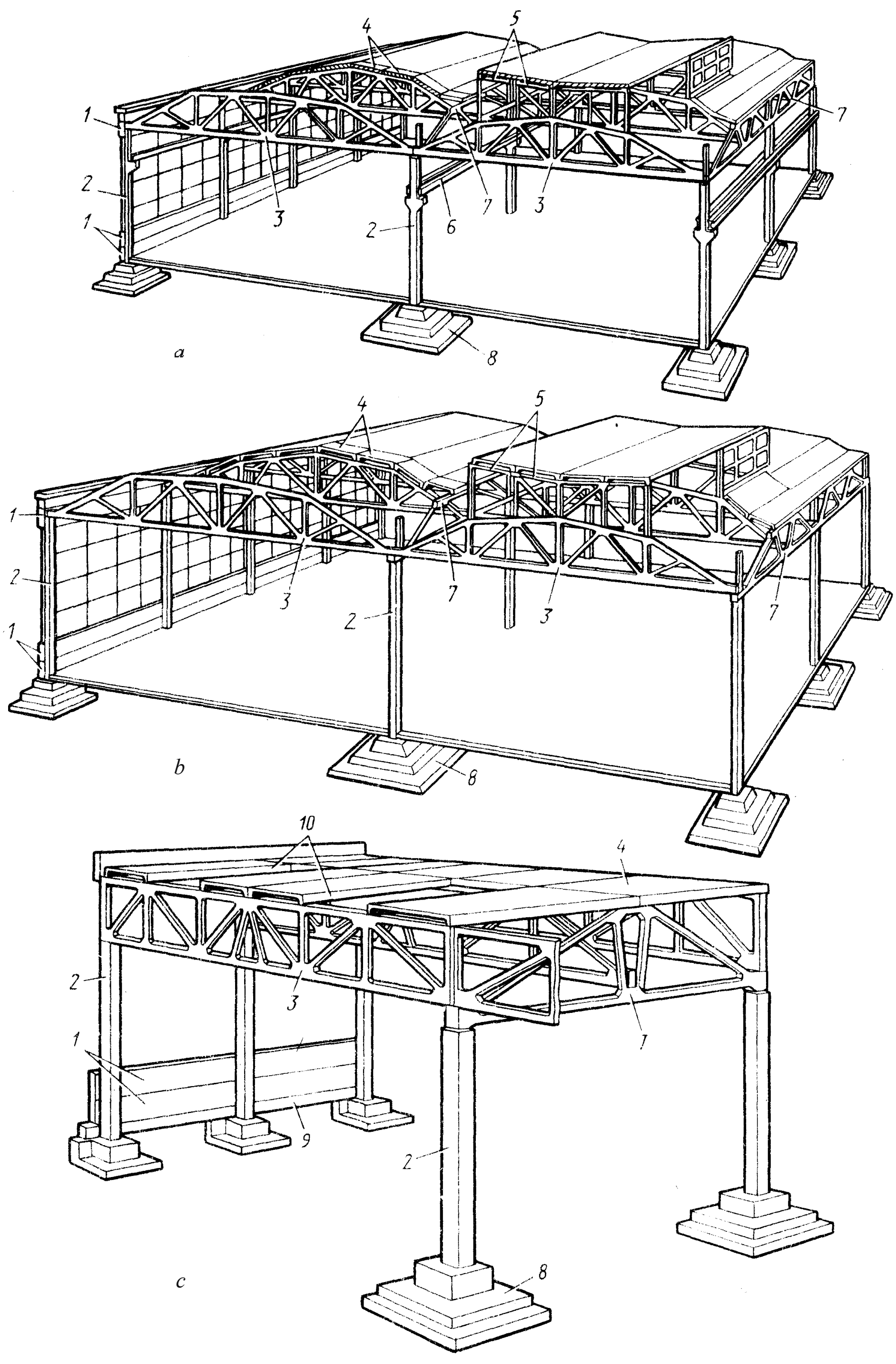


Fig. 17.1. Span structural schemes of one-storied industrial buildings [1]:
a – spans with cranes; *b* –spans without cranes: without and with a roof monitor; *c* – spans without a crane having a flat roof and skylight; *1* – wall panels; *2* – columns; *3* – roof trusses; *4* – roof slabs; *5* –steel frame of the light; *6* – a crane runway beam; *7* – secondary trusses; *8* – foundation; *9* – a foundation beam; *10* – placement locations of skylights

Buildings are represented with a complete frame formed by columns *2*, roof trusses *3* and secondary trusses *7*, crane girders *6* and roof slabs *4*. The columns rest on the single footings *8* whose overall dimensions should be taken into account when locating high-precision machine tools mounted on their own foundations as well as when specifying routes for chip removal conveyors. High longitudinal and lateral stiffness of a building frame is obtained by welding steel embedded parts and by further filling the joins with concrete. To provide light and natural ventilation there are roof monitors in the middle spans. In end spans the natural lightning is provided by means of side windows, therefore roof monitors are not needed. Enclosure structures of a building are wall panels, windows, doors and gates. In a building structures having a flat roof there are skylights used instead of roof monitors in some cases. However, similar solutions are not widely adopted since it is difficult to provide hermetic sealing of lights and they become dirty very fast.

It was mention before that equipment in modern departments is installed mostly on antivibration mounting. It provides high flexibility of a layout. Therefore floors in shops are sandwich construction including pudded earth, reliable concrete foundation mattress of 200 – 300 mm thick with iron reinforcement, leveling concrete, layer of waterproofing and floor topping.

As it was specified above, in machine building industry the preference is given to one-storied industrial buildings. However, when reconstructing some operating factories the areas of which are restricted by the existing development in exceptional cases many-storied industrial buildings are applied.

The main span construction parametres of modern industrial buildings are shown in Tab. 4.8 [1].

The type of basic and additional unified precast elements is developed for industrial building design. The size of the basic elements in the plan make 72×72 and 72×144 m, and the first size corresponds to the span length, the second – to its width. The area of the specified elements makes 5 184 and 10 368 square meters, respectively. The basic elements can be with or without cranes, with column grid 18×12 m or 24×12 m when the height of span is 6; 7.2; 8.4 m for buildings without cranes and 10.8; 12.6 m for buildings with cranes.

Besides the basic elements there are additional single- and double-span elements of 72 m long and equipped with cranes which crane span is 10.8; 12.6; 16.2 and 18 m. These spans are of 24 and 30 m wide and they are intended for placing large products.

When designing a layout, the building in the plan is represented in the form of a grid with longitudinal and lateral laying out axis (Fig. 17.2). Besides longitudinal laying out axes forming bays of the building are denoted by capital letters of the English alphabet, and lateral axis – by Arabic numerals.

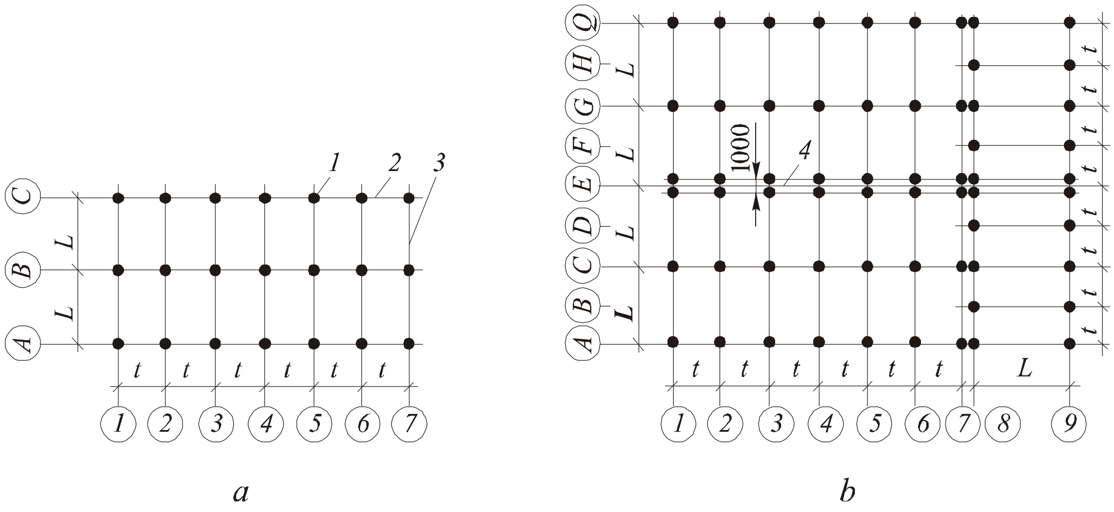


Fig. 17.2. Layouts [1]: *a* – a double-span building; *b* – a building consisting of four parallel spans and one lateral span; *1* – a column; *2* – a longitudinal laying out axis; *3* – a lateral laying out axis; *4* – expansion joint

From basic and additional elements it is possible to construct industrial buildings of different sizes and shapes. Each element is separated from the other with an expansion joint which is represented as a double row of columns (Fig. 17.2).

The variants supplemented with single- and double-span elements are used. Spans of additional elements are sometimes located perpendicularly to spans of the basic elements. It is convenient, for example, when there is an in-line assembly of articles. But more often spans of additional elements are located parallel to spans of the basic elements of the building. Similar arrangement is used in single-piece and small-scale manufacture. Sites for manufacturing base components as well as sites for assembling articles are placed in additional crane spans of greater height.

When choosing a new building layout it is necessary to use space-planning unification and structural concepts of industrial buildings. Therefore it is necessary to give preference to rectangular buildings with one-way spans of equal height mainly.

Spans of shops with increased height are necessary to group together, but the quantity of heights should be minimal. In Fig. 17.3 industrial buildings without and with cranes as well as annexes for administrative and welfare buildings are shown in section.

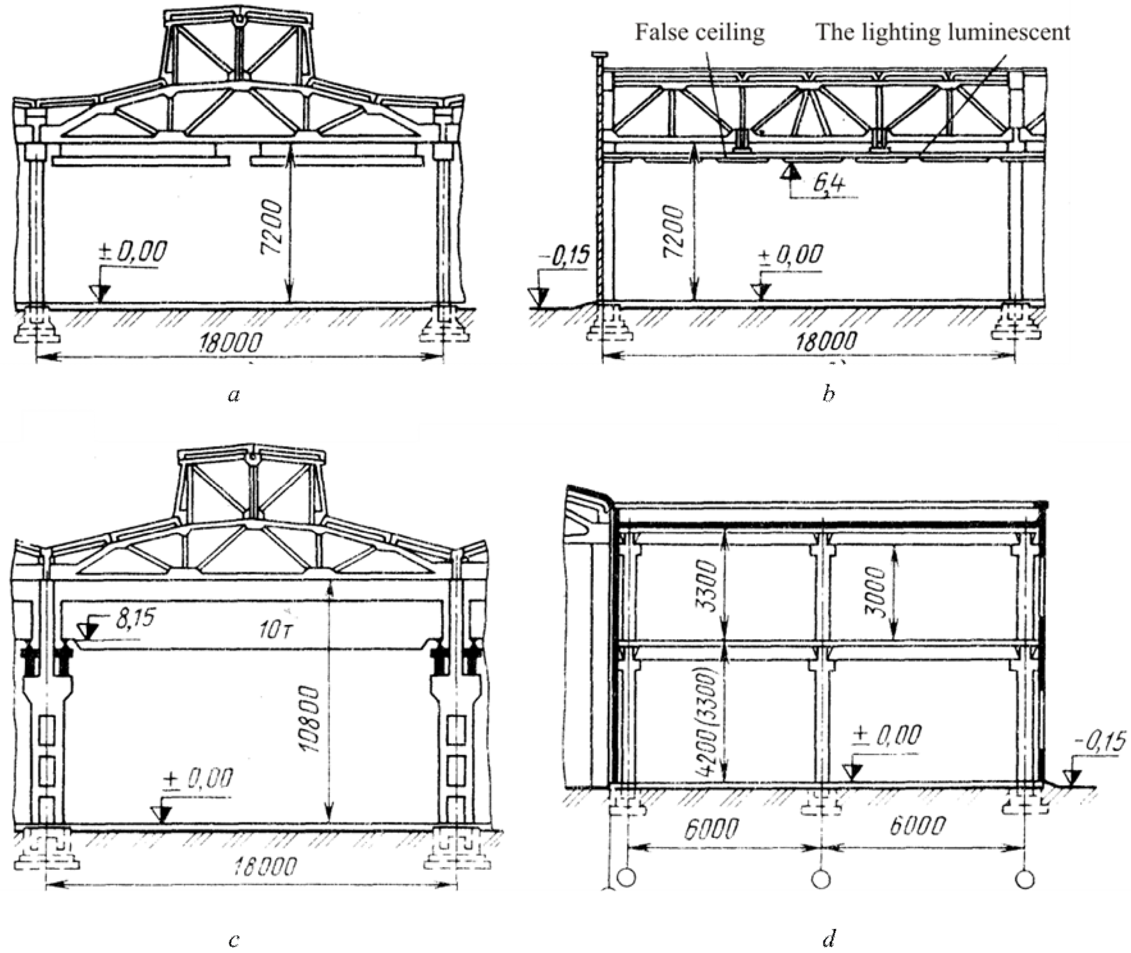


Fig. 17.3. Sectional plans of buildings [1]: a – a building without cranes having roof monitors; *b* –a building without cranes having a flat roof and a counter ceiling; *c* – building cranes; *d* – an annexe to an industrial building for administrative and welfare buildings

Buildings without roof monitors having a counter ceiling (Fig. 17.3) are applied as temperature-controlled buildings. The space between trusses is used for placing air ducts and filters for air condition systems.

In some cases construction insertions can be used in large buildings for arranging high-rise stores or other auxiliary services. In such insertions ends of railway lines, shop maintenance systems (equipment and air ducts for centralized ventilation systems and air conditioners, transforming plants, etc.) are also placed here.

Shop administrative and technical departments, welfare buildings are placed in extensions to industrial buildings (Fig. 17.3) or in separate buildings. In the latter case warm passageways to industrial buildings are provided.

The unified precast elements are developed for annexes and detached administrative and welfare buildings with a column grid of 6×6 m. The annexe is 12 m wide, detached buildings – 18 m. The length of the unified element row can be 36, 48 and 60 m. There are variants of two- three- and four-storied annexes and buildings provided, and the ground floor of annexes can be used for placing auxiliary departments. In this case the height of the ground floor can be 4.2 m. When placing administrative and auxiliary locations the storey height (floor-to-floor height) is assumed to be equal to 3.3 m.

Depending on particular conditions the annexe can be placed in the frontal building part or along the end span. The first variant is used more often. It is caused by the fact that such arrangement provides the distribution of workers all over the spans and prevents junctions of process flows and flows of workers. However, when placing storehouses for blanks or assembly lines at the end of buildings it is necessary to provide underground passages.

When placing an annexe along the end span the possibility of shop expansion is limited and it darken the span. Therefore this variant of arrangement is seldom used. Placing welfare locations in separate buildings provides greater comfort due to the best illumination, but it also increases the distance to workplaces and time loss to get from one place to another.

When choosing a building arrangement it is necessary to proceed from the total area of the shops and the accepted plan of their mutual arranging. Moreover, one should keep in mind the fact that for their technical and economic service it is necessary to organize auxiliary services. To calculate the total area of a building it is necessary to multiply the floor space $\mathbf{S_i}$ by the auxiliary service factor K_{aux} = 1.1–2. The less factor is used for large shops where the greater part of auxiliary services is placed in the administrative building (annexe), the greater factor – for small shops with high economic self-sufficiency.

Problems of unifying auxiliary services should be solved for the building structure of production. It is reasonable to create a common building for storing blanks and metals, to unify divisions for maintaining the technological, power engineering, lifting and transporting equipment.

The common systems providing machine tools with cutting fluids, chip removal, transport service, cutting tools, etc. are aimed at using the complex equipment more efficiently, reducing the amount of auxiliary workers and required area.

Updating earlier accepted layout decisions defines the overall dimensions and structure of an industrial building when arranging the whole construction.

Arrangement plans are made for each storey of the building and have the main walls, boundaries between shops and divisions, auxiliary units (transformer plants, pumping stations, air-ventilation chambers and etc.), basic lifting and transportation devices (cranes, jibs, conveyors) and their routes; basic goods traffics; the basic aisles, passages and access roads; ends of railway lines; boundaries of cellars, mezzanine floors, tunnels, main chip removal conveyors drawn on them with indicating their elevation relative to the floor level of the basic storey.

Arrangement plans are made with a scale of 1:200 and 1:400 (in some cases 1:800). They are based on the drawing of the architectural and building section without changing the accepted layout and marking of column lines, walls and other building elements.

The structure of shop departments and services, the data about their areas, the selected earlier layout diagram which defines the general production sequence as well as basic parametres and general arrangement of the building are used as input data for developing an arrangement plan.

The main principles defining the choice of shop arrangement are the following:

1. providing direct flow production, avoiding goods traffics returning when possible;
2. compactness, i.e. using a minimal floor space for arranging divisions and shops;
3. using the most cost-effective advanced types of transport;
4. minimizing transport operations for transferring articles in the process of their production;
5. the compatibility of the manufacturing processes performed at neighbouring divisions or in shops taking into account their mutual influence on product quality as well as working conditions and fire-safety measures;
6. the possibility of future expansion of the manufacture and re-arranging the equipment connected with changing or implementing new manufacturing processes;
7. using rational building arrangements from the unified precast elements.

When choosing the arrangement scheme the main thing is to provide the shortest route of the basic technological component traffics (from deriving blanks and semi-finished products to finished articles). Besides shops or factory storehouses for blanks should be placed in the building close to the blank preparation shops, and outcome of final products – near the storehouses for finished goods. As a rule divisions of technical, maintenance and tool management services are located off the basic technological flows: either in a circumferential direction of the building or along the shop boundaries inside large buildings.

Usually there are no partitions between manufacturing areas. The exception is made for temperature-controlled or fire hazardous productions. Arranging chip removal conveyors, the system of power distribution and cutting fluid supply should provide a possibility to rearrange the equipment or to replace it with a new one when changing the facilities of the plant or manufacturing technology.

Aisle ways in the *longitudinal* and lateral directions usually serve as boundaries between manufacturing areas and departments. The distance between aisle ways is not standardized; it is defined by conditions of arranging flow lines and object-closed divisions rationally. The length of divisions usually makes 35 – 50 m.

The arrangement plan of a shop (building) should correspond to the arrangement of other shops and factory services as well as to transport communications. For this purpose a general arrangement of the factory is developed. It contains an interdependent arrangement plan of all buildings, traffic arteries, utility systems with consideration for the land relief and improvement.

The structure of factory departments and services, their area as well as the production scheme defining their positional relationship are developed in the general arrangement plan.

Generally the machine-building factory consists of blank preparation shops (foundry shops, press-forging shops, shops for cutting blanks from rolled metal); processing shops (machining shops, press shops, painting shops, metal coating shops, etc.); assembly shops; auxiliary shops (tool shops, modelling shops, mechanical repair shops, electrical repair shops, construction and repair shops, research-and-development shops); storehouses; power, transportation, sanitary-engineering and general factory facilities.

The general tendency aimed at developing specialized manufactures results in creating technologically specialized factories for producing blanks, workpieces and component parts. If there are such specialized factories, machine-building factories manufacturing articles become mainly assembly enterprises and produce specific parts as well as carry out general assembly of articles.

The technological production scheme shows the interaction between factory divisions and the motion sequence of raw materials, semi-finished products and blanks in the process of their transformation into a finished article. This scheme helps to arrange shops, storehouses and other divisions of the factory rationally in order to provide the least capacity of goods traffics.

Along with the feasibility study, a preliminary general arrangement is made. At this stage the required areas of shops are defined according to technical-and-economic indexes in order to have an idea about the demanded size of the area. When designing the project of the factory composition the area and location of the divisions are updated and the final variant of the general arrangement is developed, external and internal factory transport is selected. For large factories there is a railway transport provided for external transportation, for small and medium factories – a road transport is more effective.

The general factory arrangement is started by dividing the factory territory into zones in order to arrange groups of shops having similar manufacturing processes and similar requirements for working conditions. Usually the zones are divided into zones for hot work shops, machining and assembling shops, storehouses and auxiliary shops, power and factory facilities. There is a special zone for fire-hazardous or highly explosive manufacture; it is located at a safe distance from other zones. Moreover, groups of homogeneous shops are tend to be placed in one building that results in making construction cheaper, reducing expenses for transportation, communications, heating.

When arranging shops it is necessary to consider the prevailing wind direction, to arrange shops developing dust and aerosols on leeward in relation to machining shops, factory facilities and residential areas. It is necessary to coordinate the direction of goods traffics with traffic routes of people, with bus stops outside the factory and with parking spaces for personal transport. From this point of view, entrances for transport into the building and entrances for workers are necessary to place from opposite sides. Storehouses for blanks in machine shop buildings are necessary to locate near blank preparation shops.

When designing a general arrangement plan principles of direct flow for manufacturing processes, layout compactness, use of minimal development area and communications reduction are used. The selected variant of the general arrangement should allow using the most advanced manufacturing processes and transportation systems. In most cases it is necessary to reserve the areas for future expansion of production.

The selected variant of the general arrangement is justified by technical and economic assessment. The basic technical and economic indexes characterizing the general arrangement plan are the *land-to-building ratio* $K_b = F_b / F$, the *territory usage factor* $K_u = F_u / F$, the *index of land use intensity*

$K_{li} = F_t / F$ (F_b – the building area with covered constructions; F – the total area of the factory; F_u – the area of used territory with consideration for outdoor storages, traffic arteries and sidewalks; F_t – total usable floor area of buildings with consideration for number of storeys). Also the important indexes are specific capacity of goods traffics (in kilometers/tons per 1 hectare), degree of building density (pieces per hectare), etc.

Usually the value of the *land-to-building ratio* for machine building factories is within 0.45–0.6.

Shown as an example in Fg. 17.4 there is a general arrangement diagram of a machine-tool factory where the principle of dividing a territory into zones is applied: machining, blank preparation and auxiliary shops are located in separate buildings, goods traffics and flows of workers are separated. There is a temperature-controlled department provided in the main building.

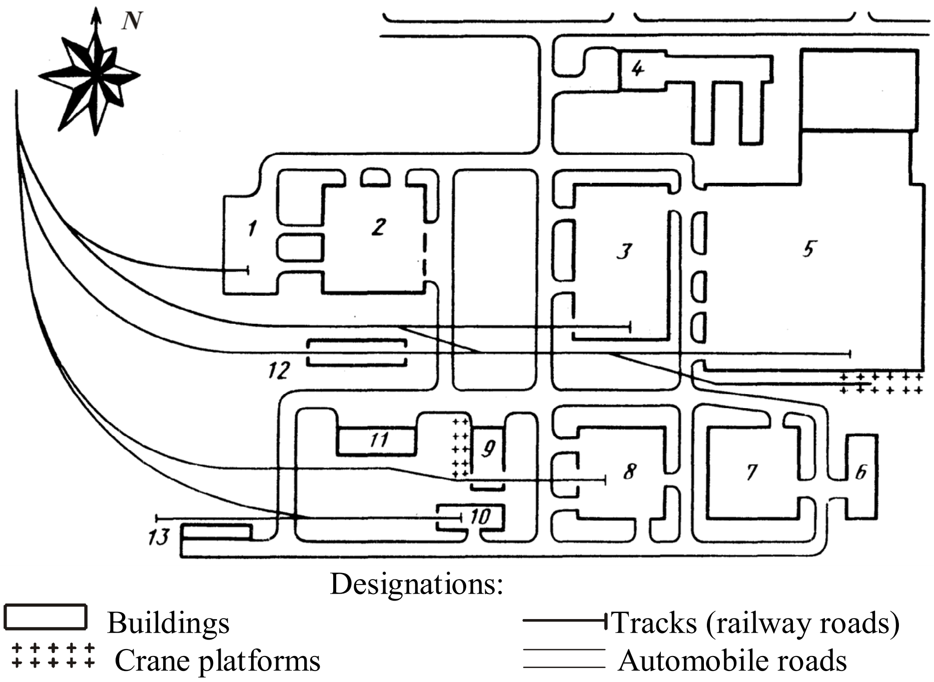


Fig. 17.4. The general arrangement diagram of a machine-tool factory [1]:
1 – a timber yard; *2* – a wood working building (with a container shop); *3* – a building for heavy machine tools; *4* – an engineering laboratory building; *5* – the main building (with a temperature-controlled shop); *6* – a storehouse for units and repair parts; *7* – a building for auxiliary shops; *8* – a building for blank preparation shops; *9* – a storehouse for metal and blanks; *10* – a storehouse for castings and forged pieces; *11* – the main store; *12* – a storehouse for finished goods; *13* – a storehouse for fuels and lubricants

Special zones on the diagram are a timber yard *1* and a storehouse for fuels and lubricants *13* which due to their fire hazards are located at a safe distance from other zones and placed on leeward with consideration for the wind streamline.

18. DEVELOPING TASKS OF BUILDING, SANITARY AND POWER ENGINEERING SECTIONS

To develop a complex detail project (further – the *project*) in all sections project engineers make design assignments for special sections of the project. When developing special sections of the technical project the basis are design assignments together with raw data on the selected area for constructing a new building or on the modernized shop, on the layout and design decisions and lists of workers [1].

The technical design assignment of dimensioning specifications includes the following sections: general information; characteristics of locations; specifications of the equipment mounted on independent foundations; requirements for the dimensioning specifications (for example, arranging bridge cranes, chip removal facilities and etc.); floor and roof loads by production machinery; composition of labour force in shops and departments.

Project engineers give the following tasks for project development of dimensioning specifications:

1. environment characteristics of the shop floor by indicating a fire danger rating level, temperature and humidity of the air environment, dustiness and etc.;
2. data on designing floors and internal furnishing of locations by defining a floor loading by the equipment, vehicles and aggressive fluids as well as special requirements for floors and furnishing of locations;
3. data on special building and construction work – the foundations for basic and auxiliary equipment;
4. data on designing noise control facilities which are made for a location with a higher level of acoustical pressure.

Except the specified raw data, to develop a project for dimensioning specifications project engineers specify places for welfare annexes, a overhead carrier loading on the load-bearing structure of the building, locations of a transformer plant, stairwells, lavatories, etc.

The specification contains information on the building: the amount of spans, their width, length and height, which spans are with or without the overhead travelling cranes, which shops and auxiliary divisions are placed in the building. Along with the explanatory note to the design assignment the building designers are given the layout drawing of the whole building with the equipment arrangement (more often in a scale of 1:100). In the general information section project engineers specify whether there are cellars – on what axis and with what mark as well as the intended purpose of the cellars and their layout drawings. The arrangement of lifting and transporting equipment in the building is also specified.

Further the specifications for particular shops and divisions can contain, for example, such information as all production equipment with mass of up to 7 tons (with the exception of some equipment under a special list) is mounted on the common concrete bedding of the whole shop. When using the automated off-track floor vehicles there are special requirements for the floor unevenness.

One-storied buildings having spans without the overhead travelling cranes are mainly used in flow-line production of tractors, cars, machine tools. Crane facilities can only be mounted in separate spans where large box-shaped workpieces are manufactured or heavy units are assembled. Crane spans are often used in FMSs to provide space planning flexibility. The distance to the bottom of the load-bearing structures can be selected in accordance with the current standards. The building is often designed by using identical spans and identical height in order to apply the unified spans and standard constructional elements that can accelerate the process of construction.

The industrial building can be constructed by using precast reinforced constructions or steel constructions. This question is solved at the stage of construction design with consideration for technology requirements.

The foundations for reinforced concrete columns or steel columns of industrial buildings are made from step-type reinforced concrete constructions. The sizes of the foundation bedding depend on equipment loads and ground conditions. When designing a layout of the equipment mounted on separate foundations it is necessary to take into account the sizes of the column and equipment foundations. The sizes of reinforced concrete column sections are assumed not less than 300×300 mm.

In the cutting tool restoration departments and in offices for gauge work and quality inspection partitions are made from glass but the lower part of them is made of steel and is 1 m high. The whole partition is 2.5 – 3 m high. In welfare rooms and offices the wooden or steel (in some cases) partitions are used. Doors and gate for going outside or to a staircase are placed from the most remote workplace at distances satisfying the norms of safety requirements (usually not more than 25 m). Escape doors should open in the direction of travel (exit) from the building.

The width of the gate is usually bigger than the width of transport for not less than 600 mm and it should be not less than 1.8 m. The height of the gate should be more than the height of transport for 200 mm and on the whole it should be not less than 2.4 m. To protect from cold air there are air curtains installed above entrance or exitways. Staircases to the upper floors of welfare spans are arranged at the distances satisfying the norms.

Basically all shop equipment is mounted on the common concrete bedding made of a reinforcement mesh 250×250 mm with iron rods 250 – 300 mm thick. The equipment having varying dynamic loads, for example: planing, face grinding and other machine tools as well as the equipment weighing more than 7 tons is usually mounted on the separate foundations (according to the list enclosed to the explanatory note).

Machine tools with A and C accuracy rating and measuring devices for which even small-amplitude oscillations are inadmissible are installed on special antivibration mounting. Integration (assembling) benches for assembling high precision articles are mounted on the same foundations. These foundations should be placed at a certain distance from the load-bearing structures – columns and walls. The foundations for such equipment are designed by construction departments of design institutes. Drawings of the foundations for automatic transfer lines are made by the same organization which designs transfer lines.

The piled foundations ensure higher vibration insulation when the base has high stiffness. The foundations of this type are also applied for the equipment with heavy portable units, with unbalanced parts, and also for the equipment working with fast reverses of separate units.

The foundations on rubber mats are also applied. As it is shown in Fig. 18.1 KV-1 and KV-2 mats are used as vibration insulation elements. The concrete block can be fixed directly on the surface of a mat which is coated with waterproofing paper and a black sheet.

The mats are 21 – 26 mm high with the area 350×350 mm. The foundations on rubber mats are applied for mounting machine tools with B and A accuracy rating and for the equipment whose foundation slab is not stiff enough or with strong dynamic vibrations.

To reduce vibrations the foundation is made heavy and it is separated from the basic foundation with through joints. The disadvantages of such foundations are structural complexity and considerable overall dimensions in the plan. However, the solidity of the foundation ensures reliable installation of the equipment and high accuracy of its operation. The foundations on springs are the most reliable in aspect of vibration insulation, but they are also the most expensive, they are applied only for mounting machine tools with C accuracy rating, high precision measuring machines and etc. In this case the concrete block is put on the springs which function like a mat.

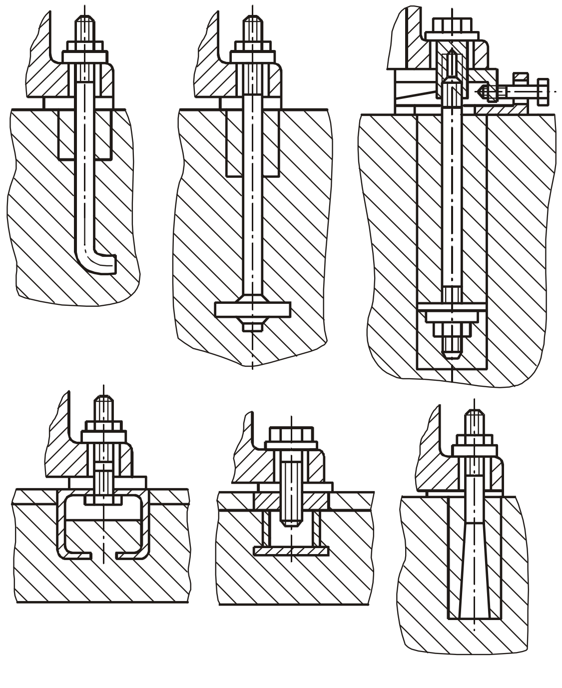
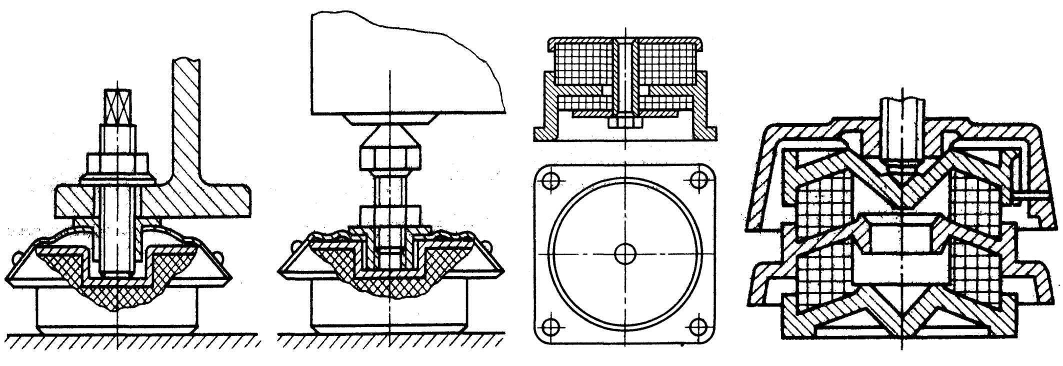


Fig. 18.1. Ways of fastening equipment to the foundations

The sizes of the foundations in the plan are defined in accordance with the sizes of the basic equipment. The distance from a profile plane of the foundation base to the foundation boundary should be not less than 100 mm, and the distance from well boundaries for anchor bolts to the foundation boundary – not less than 200 mm. The equipment which is to be installed on specially designed foundations of one of the types shown above, is fastened, as a rule, to the foundation with anchor bolts (Fig. 18.1) that considerably enhances the stiffness of the foundation slab (up to 10 times).

When installing machine tools with N and P accuracy rating and some machine tools with B accuracy rating it is possible to use only antivibration mounting (Fig. 18.2). Their application provides the demanded quality of manufactured parts after machining, and simplifies rearrangement of machine tools.



a *b* *c* *d*

Fig. 18.2. Antivibration mounting for installing precision equipment

Elastic elements in such mounting which provides vibration isolation from neighbouring equipment are: with a natural frequency of system oscillations of more than 20 Hz – felt, cork, rubber-covered canvas, plastics reinforced with fibrous materials, lead-asbestos-type gaskets; with frequency 20–10 Hz range – rubber, wire mesh of big width, thick felt and cork gaskets; with frequency 10–50 Hz range – rubber (working in shear), wire mesh of big width; with frequency less than 5 Hz – spiral and flat springs, air legs.

A good floor covering is tiles with marble chips. Cast-iron or concrete tiles are also applied on the main access roads, but cast-iron tiles are more solid. Road surfacing depends on particular usage conditions and it is coordinated with project engineers.

When choosing a floor covering it is necessary to consider its resistance to chemical attacks, i.e. influence of hydraulic fluids on it – water, mineral oil and emulsion, alkaline solutions, gasoline, kerosene, etc., as well as water resistance, wearability, noiselessness.

Many-storied buildings are designed when the manufacture requires relatively small-size equipment or when the factory territory is restricted.

The sanitary-engineering design section of the project contains such parts as: water supply for sanitary-welfare needs, sewerage, ventilation, treatment facilities, installations for air conditioning in temperature-controlled rooms, etc.

In the specification for water supply and sewerage the data about water need and consumption for industrial needs and about possible sewage discharge is indicated.

In machine-assembly shops water is consumed both for industrial (technological), and domestic needs. For industrial needs water is consumed for preparing cooling fluids, washing articles, cooling and hardening in HFC installations, hydraulic tests, for hydrofilters in air conditioners and paint machines, steam generation for industrial needs. Degree of water treatment used for industrial needs is defined by particular conditions of consumption.

For domestic consumption the treated water, suitable for human consumption, is used in automatic drinking bowls and drinking water fountains, in shower rooms, washstands, lavatories and etc.

Water consumption is calculated for each type in accordance with specially made consumers' sheet which should contain the following data: the code number of the equipment consuming water on a layout drawing; the name of the shop and division; total and daily water flow (m^3) per equipment unit with consideration for the equipment load factor; type of equipment work – varying volumes of water consumption; volume of water dumped in the water drain (the chemical name, its contents in the solute, characteristics of the dumped solutes, etc.). It is extremely important not to discharge the polluted water from treatment facilities, since it is hazardous to human health, animals and plants.

The heating and ventilation design section contains the shop work schedule; the list of the equipment requiring local vents; supporting information on the necessity for air curtains above doorways; the temperature which should be maintained in the shop; the amount of the sluggish metal going into the shop (on average per shift); the gates sizes and the time of their opening (number and duration of opening per shift).

The heat and power design section is aimed at developing systems to supply the shop with compressed air, engineering steam and other energy carriers. For this purpose the project contains the estimated data on the necessities for compressed air, engineering steam and etc. The steam is used for process needs: heating up of cooling (cutting) fluids while preparing them and water in jet washers, in drying cabinets, for heating systems, etc. The list of steam consumers is made with indicating the data which is necessary to define annual consumption for each consumer, shop and division. For the purposes specified above steam is used at pressure of 150 – 400 kPa. If it is necessary to supply steam under high pressure, there can be a construction project of a boiler-house designed, and it should be coordinated with the board of boiler and pressure vessel inspectors.

The electric power design section is aimed at developing systems to supply the shop with electric power. It contains the following information: the intended locations for transformer plants; the specification of the accepted equipment indicating its power; a fire danger rating level. For designing an electric power supply system for machine assembly production a list of consumers is made in accordance with divisions placed in the building. The position of each electric power consumer is specified in the list, and the electric power consumption is divided between welfare and industrial locations. Summary lists specifying a quantity of the equipment and the installed power capacity for shops and departments are made according to the enumerated divisions of electric power consumption.

When determining fire danger categories and classes project engineers comply with industry standards considering type of production in the shops. Mechanical assembly manufactures are mainly related to category E, however some sites can be related to categories C and D. Places for automatic fire-extinguishing equipment should be located on the ground floor having an emergency exit and the area of 40 m^2 for gas extinction and 100 m^2 for foam extinction.

When designing special sections of the technical design assignment it is necessary to pay great attention to designing ***communication and signalling systems*** without which modern mechanical assembly production cannot be implemented. The data for developing communication and signalling systems contains an equipment layout indicating the places for installing devices;

information on quantity and type of communication installations; a design assignment for a dispatch control system; the locations of video cameras, electric clocks and public loudspeakers.

In modern mechanical assembly manufacture the following main types of communication are obligatory:

1. general-purpose communications (automatic telephone exchange, television, electric clocks (time electrical distribution system);
2. administrative-economic communication (computer networking, intrafactory automatic telephone exchange, communication installations for the chief dispatcher, shop dispatch operators, director, deputy directors, chief engineer and chief production manager, industrial television);
3. special-purpose devices (fire alarm systems and security alarm systems, special communication commutator, etc.).

19. ECONOMIC FEASIBILITY OF PROJECT

Design of a machining or assembling shop is completed by choosing an optimum variant of the project, defining its technical and economic indexes and making an explanatory note.

When choosing an optimum variant of the shop design it is necessary to be oriented to the project having minimum reduced expenditures.

Reduced expenditures consist of the cost price of manufacturing products (C) and the products of standard effectiveness ratio of capital investments ($E_n = 0.15$) and capital costs (K). When defining capital investments it is necessary to consider the cost of all basic and an auxiliary equipment including transportation and preparation operations and mounting, the cost of the total shop area, the cost of circulating assets in incomplete production, expenditures for housing and public amenities building construction, etc.

When calculating the cost of the total shop area the cost of 1 m^2 of the area should be taken into account (at the preliminary stage of calculation it is assumed equal to 10 000 – 20 000 roubles).

More generally the shop cost price of manufacturing products looks like [1]:

$$C = M + S + E + Am + T + At + Ad + O, \qquad (19.1)$$

where M – expenditures on materials or blanks; S – wage-and-salary disbursements for industrial workers including social insurance and holiday; E – operational cost of basic equipment; A – depreciation expense for basic equipment; T – operational cost of cutting tools; At – depreciation expense for machining attachments; Ad – expenditures for equipment adjusting; O – general shop expenditures.

Expenditures on materials and blanks are defined with consideration for cost of scrap. If two variants of manufacturing processes being compared are to produce parts from the blanks made with the same method, the cost of the blanks can be not included in the production cost. If methods being used are different, it is necessary to include the cost of the blanks. The cost of the blank is defined in accordance with the reported data of the corresponding shop of the factory or, if the blanks were bought elsewhere, according to the price-lists, depending on the mass and complexity of the blanks. It is necessary to add to listed prices 5 – 10 % for transportation and preparation operations.

Wage-and-salary disbursements for industrial workers are defined on the base of time standards for the given operation, qualifications of workers (skill-category) and base wage rate:

$$S = R \times t \times P, \qquad (19.2)$$

where R – hourly base wage rate defined in accordance with the skill-category, specified in the operation process chart; t – labour input of operation performance, minutes; P = 1.5... 1.7 – factor considering performance of norms, expenses on social insurance and payment of holidays as well as the rate of additional payment.

Operational costs of the machining equipment include electricity costs, costs of cutting fluids.

The maintenance cost price can be determined using norms of unified system for scheduled preventive maintenance. According to this system the maintenance cost price of the equipment of each standard size is defined by a category of maintenance complexity R and by the duration of the inter-repair cycle.

The costs of lubricants and cutting fluids are rather insignificant, and in usual conditions they can be neglected.

Amortization expenses for equipment are defined proceeding from the amortization factor (usually 0.15) and equipment costs. For general-purpose equipment this value is defined by norms, and for special-purpose equipment – by the annual programme of the parts machined on it.

Operational costs of the cutting tool for one operation are calculated proceeding from the initial cost of the tool, the quantity of repeated grinding, the cost price of one repeated tool grinding, actual cost of the tool between two regrinding, duration of tool work for one operation. At multitooling setup it is necessary to determine operational costs of each tool and sum up the received values.

The cost price of attachment maintenance is determined proceeding from the fact that expenditures for industrial equipment should be shared out among the total number of the articles which should be produced within two years. Consequently, annual depreciation amount makes 50 % of attachments cost. It is possible to assume the value of annual expenditures for maintaining attachments equal to 8–10 % of their cost, then annual expenditures for maintaining attachments will make 58–60 % of their initial cost.

Expenditures for compressed air and the electric power used in attachments can be neglected.

As life time *of general-purpose* attachments is rather long, and expenditures for one process are insignificant, so this component of the technological cost price can be neglected.

Expenditures for equipment adjusting are calculated proceeding from the expenditures for start-up man' salary for a time unit, duration of a machine setup, minutes; the factor of labour cost considering the performance of norms, expenditures for social insurance and payment of holidays, the quantity of operations executed during one adjustment.

It is necessary to notice that if the number of readjustments is 6 – 24 in a year, expenditures for adjustment are considered to be small; for flow-line production when a certain process is performed by certain equipment, expenditures for readjustment are neglected.

Expenditures of shop auxiliary systems are also included in total shop expenditures.

When estimating the project quality it is necessary to check if the basic indexes stipulated by the technical design assignment are performed and if the technical decisions taken in the project meet the technological design standards, the requirements of scientific management of labour, occupational safety and health and environmental protection. The indexes used for estimating the project quality are the following:

1. the basic indexes – annual output in wholesale prices, in physical terms, net (standard) production in wholesale prices; labour force in break-up into workers, engineers and technicians and office personnel; the basic industry and production assets; capital investments in basic industry and production assets; labour input of output products;
2. indexes of the technical level, technology, mechanization and automation of production – the amount of basic equipment; percentage of advanced, low-waste kind of blanks applied; capital equipment per unit of labour for employees; stock utilization ratio; the level of mechanization and automation of production processes (%), which is defined as a ratio of the sum of all machining time (machine tool-hours) to the sum of all machining floor-to-floor time (hrs);
3. indexes of organisation level of labour, production and management – labour productivity (manufacture of standard-net products) per one worker; operation rate of the equipment; capital productivity ratio (manufacture of standard-net products per 1 rouble of the fixed capital assets); factor of manufacture cooperation; amount of computer facilities applied for management and organization of manufacture; availability of shop management system; total labour input of the most important articles;

4. indexes of the project efficiency level – total cost of production; cost price of the most important articles; profitability; capital cost repayment period; efficiency of project implementation per 1 rouble of design expenditures;
5. indexes of social factors and working conditions – availability of decisions for providing ergonomically favorable working conditions; percentage of workers occupied in manual labour in relation to the total labour force; availability of decisions for environment protection and use of production wastes; availability of own technical decisions protected by copyright certificates;
6. indexes of project completion – completeness of documentation and its conformity to normative documents for the order of development and approval; conformity of the documentation completion to the requirements of standard documents.

Defining the project quality category is made in accordance with the merit point system taking into account the weightiness coefficient for each group of indexes.

ACRONYMS AND ABBREVIATIONS

ACS – automated control system
APCS – automatic process control system
ATMS – automated tool management system
ATS – automated transport or transport-storehousing system
AWDS – automated waste disposal system
CAD – computer aided design
CF – cutting fluid
CFL – central factory laboratory
CIMS – computer-integrated manufacturing system
CLS – combustibles and lubricants storehouse
CML – central measuring laboratory
CSRP – Customer Synchronized Resource Planning
CAIS – computer-aided inspection system
DCC – data-computing center
DPP – Day-to-day production planning
EMRMS – equipment maintenance and repair management system
ERP – Enterprise Resource Planning
ETP – engineering and technical personnel
FAW – flexible automated workshop
FMAF – flexible manufacturing automated factory
FMC – flexible manufacturing cell
FMM – flexible manufacturing module
FMS – flexible manufacturing system
FR – feasibility report
FTL – flexible transfer line
GOST – Russian state standard specification
GPS – generative planning system
JL – junior labour
MRP – Manufacturing Resource Planning
MT – machine tool
NC machine tool – Numerically Controlled machine tool
OP – office personnel
PC – power cabinet
PSS – production supporting system
QCD – quality control department
RTC – robotized technological complex
SCCS – supervisory computer control system
TEC – technical and economic calculation
TEI – technical-economical index
UPE – unified precast element

REFERANCES

1. Мельников Г. Н., Вороненко В. П. Проектирование механосборочных цехов. М.: Машиностроение, 1990. – 350 с.
2. Егоров В. А. Автоматизация проектирования предприятий. Л.: Машиностроение, 1983. – 327 с.
3. Проектирование машиностроительных заводов и цехов: Справочник. В 6 т./ Б. И. Айзенберг, М. Е. Зельдис, Ю. Л. Казарновский и др. М.: Машиностроение, 1974, 1975.
4. Чернко Д. В., Хабаров Н. Н. Основы проектирования механосборочных цехов. М.: Машиностроение, 1975. – 348 с.
5. Петкау Э. П., Матвеев В. С., Журавлев В. А. Проектирование машиностроительного производства: Учебное пособие. – Томск: Изд-во ТПУ, 2002. – 199 с.
6. Укрупненные типовые нормы времени на работы по ремонту металлорежущего оборудования (по видам ремонта). Под. ред. Комарова Н. Л. – М., Экономика, 1990. – 66 с.
7. Королёва Н. И. Организация производства на предприятии: Учебное пособие. – Томск: Изд-во ТПУ, 2005. – 156 с.

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