TOMSK POLYTECHNIC UNIVERSITY

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MACHINE SHOPS DESIGN

Methodological instructions for self-study

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Methodological instructions for self-study on discipline
“Machine Shops Design”

Section numbers correspond to sections of the study aid by
Kozlov V.N., Pichugova I.L. “Machine shops design”

Sections 1 – 2

1. What is a workshop?
2. What is a production floor?
3. What is a production cycle?
4. What are the main stages of production?
5. What is flow-line production?
6. What is a batch?
7. What is the total floor space of a workshop?
8. What is direct labour?
9. What are the engineering, technical and office personnel?
10. What is junior labour?
11. What is the difference between shop arrangement and shop layout?
12. What is ‘column space’ and ‘width of span’?
13. What is non-line production?
14. What does the basic section of the machine shop design contain?
15. What does the special section of the machine shop design contain?
16. What is auxiliary labour?

Section 3

1. Enumerate the sequence of designing machine shops.
2. What problems should be solved when designing machine shops?
3. Enumerate the tasks which are solved at pre-design stage.
4. What are the main sections of the machine shop design?

Section 4

1. What problems are solved by a CAD system when designing divisions and shops?
2. What is the structure of providing CAD system?
3. Draw the CAD system block diagram.
4. What are the main sections of the machine shop design?
5. What is the base of a CAD system?
6. What is the main function of a CAD system?

7. What are the basic directions of modern requirements to design?
8. What factors influence on the quality of a project?
9. What is it necessary to create in order to develop standard-methodical support of a CAD system?
10. What is the basic difference between a CAD system and a traditional design system?

Sections 5 – 6

1. What principles is it necessary to adhere when designing shops?
2. Describe how to determine a type of production.
3. Describe each type of production.
4. What are the ways to automate manufacture?
5. What are FMS, RTC, FMM, FTL, FMC, FMAF?
6. Draw a production efficiency graph depending on manufacturing automation. Specify the type of the equipment used.
7. Enumerate construction and installation measures in order to increase flexibility of production.
8. Enumerate raw data for shop reconstruction.
9. Enumerate stages of calculating labour input to machine the annual program for all parts in the shop when designing a shop for small-scale production.

Section 7

1. What is the working mode?
2. What is the actual time arrangement? What are the norms for different quantity of working shift?
3. What is the annual actual time arrangement of the worker for 41 hrs working week?
4. Does the annual actual time arrangement of the worker depend on the quantity of working shift?

Sections 8 – 9

1. What is the batch?
2. What does the batch size influence on?
3. Describe how to calculate floor-to-floor time for one operation (process)?
4. Describe how to calculate total floor-to-floor time for operation (process)?
5. What is plant schedule?
6. Describe how to calculate the batch size.

7. What is the machine-setting (preparatory-final) time? What does it consist of?
8. Describe how to calculate the demanded amount of one type (j-type) of the machine tools in the shop?
9. What is technological process synchronization? What ways of it are there?
10. Enumerate methods of labour intensity calculation.
11. Enumerate advantages and disadvantages of labour intensity calculation according to the method of the reduced program.
12. Enumerate advantages and disadvantages of labour intensity calculation according to the method of the specific labour input.
13. Enumerate advantages and disadvantages of labour intensity calculation according to the method of using the factory data.

Section 10

1. Describe how to calculate the demanded amount of the machine tools in the shop.
2. Enumerate advantages and disadvantages of calculating the required amount of equipment according to technical-and-economic indexes.
3. What is technological process synchronization? What ways of it are there?
4. Enumerate methods of calculating the required amount of equipment.
5. What is the operating ratio of the given type of the equipment? Describe how to calculate it.
6. Describe how to calculate the demanded amount of one type (j-type) of the machine tools in the shop.

Section11

1. Describe the methods of an equipment layout.
2. Describe the methods of arranging the equipment relative to the aisle way.
3. Describe the norms of arranging the equipment relative to the aisle way.
4. What is the width of main access roads for intershop transportation?
5. What is the width of footpaths?
6. What classes is equipment divided into for rating distance from the objects?

Sections 12 – 14

1. What is a production floor?
2. What does the specific production area influence on?
3. Describe how to calculate the total production floor space.

4. What does workplace organization depend on?
5. What does the total production floor space include?
6. How can equipment be located relative to the aisle way?
7. What is the specific production area? What does it include?
8. What classes of machine tools accuracy are there? What does it influence on?

Section 15

1. Describe how to calculate the required amounts of direct labour.
2. Describe how to calculate the required amounts of auxiliary labour.
3. Describe how to calculate the required amounts of office workers.
4. Describe how to calculate the required amounts of junior labour.

Section 16

1. What does the auxiliary system consist of?
2. Describe the types of storehouses according to the level of mechanization.
3. Describe the types of storehouses according to the form of storing.
4. Describe the types of storehouses according to their intended purpose.
5. Describe the types of the transport service according to their intended purpose.
6. Describe how to reduce the volume of goods traffic in the shop.
7. How is the volume of goods traffic shown in the shop layout?
8. What functions does the tool management service perform?
9. What is the structure of the tool management service?
10. What functions does the repair and maintenance service perform?
11. What is the structure of the repair and maintenance service?
12. Describe how to calculate labour input of annual maintenance of all machine tools in the shop.
13. How does a chip removal system work?
14. Describe how to calculate the expected amount of chips in the shop.
15. How does the coolant supply system work?
16. What functions does the quality inspection service perform?
17. What is the structure of the quality inspection service?
18. What functions does the consumer service and labour safety service perform?
19. What is the structure of the consumer service and labour safety service?
20. What functions does the production preparation and management service perform?

21. What is the structure of the production preparation and management service?
22. What functions does the dispatching system perform?
23. Why is it necessary to adhere to the recommended spans of management?
24. How many persons should one manager control?
25. How many persons should one foreman control?
26. How many persons should one job foreman control?
27. What is enterprise resource planning (ERP)? What is it intended for and what limitations are there?

Section 17

1. What configurations and types of shop buildings are there? What are they intended for and what limitations are there?
2. What are the main principles influencing on the selection of a shop arrangement?
3. How is it necessary to group spans of shops with increased height?
4. What are the basic technical-and-economic indexes characterizing the general work program of the factory?
5. What is the value of the land-to-building ratio for machine building factories?
6. Describe how to calculate the land-to-building ratio of the factory.
7. Describe how to calculate the territory usage factor of the factory.
8. Describe how to calculate the index of land use intensity of the factory.
9. When is it obligatory to use partitions between manufacturing areas?
10. What usually serves as boundaries between manufacturing areas and departments?
11. How long is a production division (site)?
12. What it is necessary to do first for the general factory arrangement?
13. What types of zones it is necessary to pay special attention to?
14. Describe how to place homogeneous shops in the factory territory. Why?
15. Enumerate types of shops with homogeneous purpose.
16. Describe the factory zones.

Section18

1. Enumerate the tasks which project engineers give for project development of dimensioning specifications.
2. Enumerate the content of the project specification.
3. Where can the crane facilities be mounted?
4. What materials are used for the foundations?

5. Write the sizes of reinforced concrete column sections.
6. Enumerate types of antivibration mounting.
7. Describe how to fasten equipment to the foundations.
8. What does the sanitary-engineering design section of the project contain?
9. What does the heating and ventilation design section of the project contain?
10. Enumerate design sections of the project contain.
11. Enumerate main types of communication which are obligatory in mechanical assembly manufacture.

Section 19

1. What do reduced expenditures of the project include?
2. Describe how to calculate the shop cost price of manufacturing products. Explain each component.
3. Describe how to calculate wage-and-salary disbursements for industrial workers. Explain each component.
4. What indexes are used for estimating the project quality?

Sections 10-19

1. What is the reduction coefficient? Describe how to determine it.
2. Describe how to calculate the required amount of machine tools.
3. Describe how to calculate labour input according to the resulted program.
4. Describe the basic types of shops arrangement, their advantages and disadvantages.
5. Describe time arrangement of the equipment.
6. Describe how to calculate production floor space.
7. Describe how to calculate the total floor space.
8. Enumerate the measures for increasing manufacture flexibility.
9. Describe the variants of arranging the equipment, their advantages and disadvantages.
10. What does the machine shop layout of the auxiliary services include?
11. What are the main principles influencing on the selection of a shop arrangement?
12. What configurations and types of shop buildings are there? What are they intended for and what limitations are there?

Methodological instructions for designing a shop

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

1. A production program for each part (the name and the annual production program).
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 program can be: 1) accurate; 2) reduced; 3) conditional.

1. *Design under the accurate program* 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 program* 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:

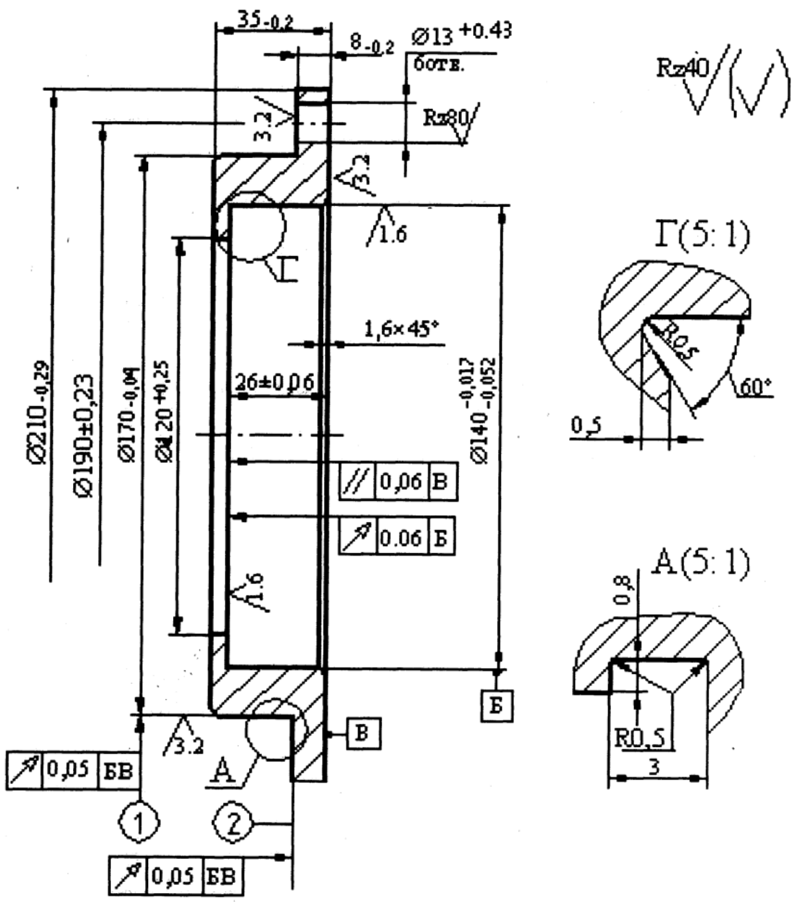
- All drawings are divided into groups according to their constructive-technological similarity. Usually they are groups of shafts, sleeves, disks, case-shaped parts, gear wheels and etc. The similarity of manufacturing process and used machine tool types and attachments lies at the heart of division 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.

Calculating labour input to process the annual program of all parts in the shop, required quantity of equipment and floor space of the site

1. Sort the drawings of the parts machined in the shop within 1 year into groups in accordance with their constructive and technological similarity;

2. Draw the complex part for each group containing surfaces which are typical for the group of parts under consideration (see Fig. 1);



1. H14, h14, J_s14.
2. HB 220…260.
3. Cast iron 25.

Fig. 1. Working drawing of the disk

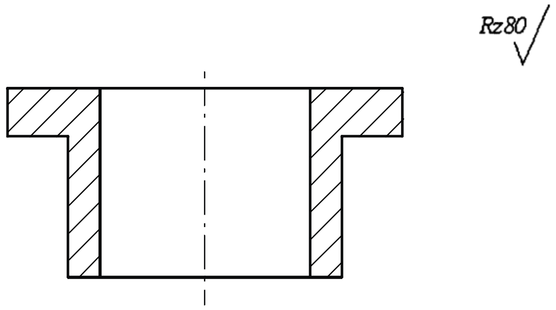
3. On the drawing of the complex part it is necessary to specify mid-of-tolerance sizes and required processing accuracy, roughness and surface-to-surface accuracy which are typical for the considered group of parts. The annual program is equal to the biggest annual program among all parts of the group;

4. Make a manufacturing route of the complex part, the required equipment (machine tool model) for each operation and an operational sketch of processing.

Technological process of machining a disk (or a sleeve)

Operation 0 (blanking):

1) Mold the disk blank.

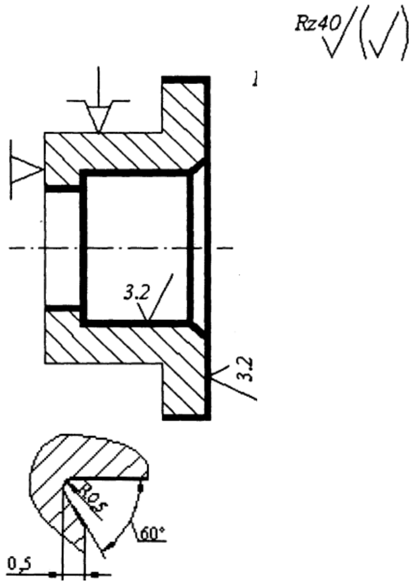


1. H14, h14.
2. HB 220…260.

Fig. 2. Operation drawing of the blank, operation 0.

Operation 1 (turning, 16K20):

1) Mount a blank in an universal 3-jaw chuck;
2) Turn off the right face end (1) of the blank (side A) L = 38h14($_{-0.62}$) mm;
3) Turn off the surface (2) Ø210h11($_{-0.29}$) mm;
4) Bore off the surface (3) Ø120H11($^{+0.25}$) mm;
5) Bore off the surface (4) Ø138H11($^{+0.25}$) mm roughly, machined surface (5) L = 14.2h14 ($_{-0.62}$) mm;
6) Bore off the surface (4) Ø139.5H9($^{+0.1}$) mm semifinishedly, machined surface (5) L = 14.2h14($_{-0.62}$) mm ;
7) Bore off the surface (6) L = 1.6h14($_{-0.62}$) mm;
8) Bore off an overtravel *A* on the surfaces (4) and (5);
9) Take off the blank and put the processed workpiece in the container.

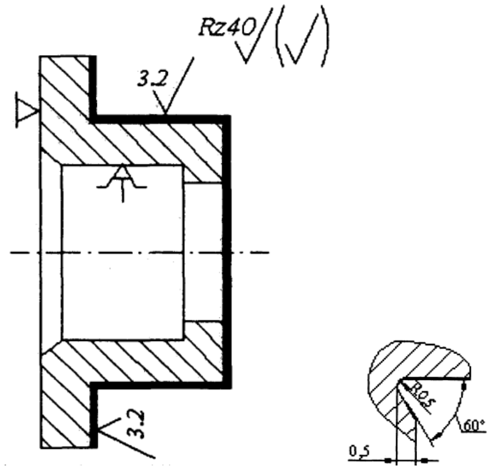


1. H11, h11.

Fig. 3. Operation drawing of operation 1.

Operation 2 (turning, 16K20):

1) Mount a blank on an self-centering mandrel;
2) Turn off the face end (1) of the blank (side B) L = 35h12($_{-0.25}$) mm;
3) Turn off the surface (2) Ø172h11($_{-0.25}$) mm roughly, machined surface (3) L = 8.4h14($_{-0.36}$) mm;
4) Turn off the surface (2) Ø170.5h9($_{-0.1}$) mm semifinishedly, machined surface (3) L = 8.2h14($_{-0.36}$) mm;
5) Turn off an overtravel *A* on the surfaces (2) and (3);
6) Take off the blank and put the processed workpiece in the container.

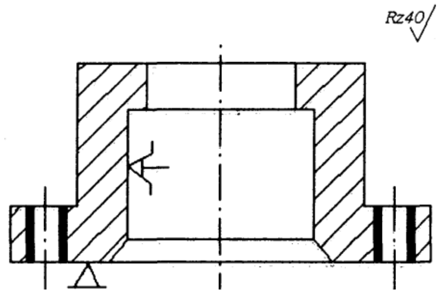


1. h11.

Fig. 4. Operation drawing of operation 2.

Operation 3 (drilling, 2118):

1) Mount a blank on an self-centering mandrel;
2) Drill 6 holes Ø13H14($^{+0.43}$) mm on ¢190J$_s$12(±0.23) mm simultaneously by using drill box and 6-spindle drilling head;
3) Take off the blank and put the processed workpiece in the container.



1. H14.

Fig. 5. Operation drawing of operation 3.

Operation 4 (metal workshop):

1) Filing sharp ends of the workpiece.

Operation 5 (cylindrical grinding, 3M151):

1) Mount a blank on an self-centering mandrel;
2) Grind the surface (1) Ø170h7($_{-0.04}$) mm definitively, machined surface (2) L = 8h13($_{-0.22}$) mm ;
3) Take off the blank and put the processed workpiece in the container.

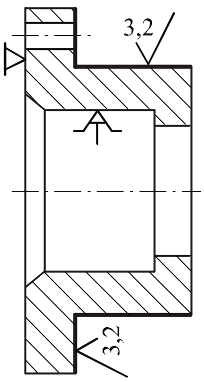


Fig. 6. Operation drawing of operation 5.

Operation 6 (internal grinding, 3K228B):

1) Mount a blank in an collet chuck;
2) Grind the surface (1) Ø140N7($_{-0.052}^{-0.017}$) mm definitively, machined surface (2) L = 26J$_s$11(±0.06) mm ;
3) Take off the blank and put the processed workpiece in the container.

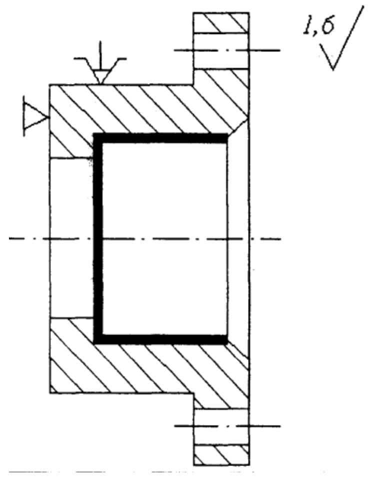


Fig. 7. Operation drawings of operation 6.

Operation 7 (metal workshop):

1) File sharp ends of the workpiece.

Operation 8 (washing):

1) Wash the part.

Operation 9 (controlling):

1) Check the part.

5. Specify cutting tools, feed rate, calculate cutting speed and operation time for all machining passes of each operation. Base time, minutes, is calculated for each technological pass. Base time, which is necessary for stock removal, minutes, is calculated for turning, grinding and drilling operations by the formula $t_b = L/(s \times n)$,
where L – the length of machined surface (in direction of feed s); s – feed rate, mmpr; n – frequency of spindle rotation, rpm.
For milling operation base time, minutes, is calculated by formula $t_b = L_w / s_m$, where L_w – working length (in direction of feed s) taking into account the diameter and tooth entrance length of a milling cutter; s_m – feed per minute (mmpm) which is calculated by formula:

$$s_m = s \times n = s_z \times z \times n$$

where n – frequency of a milling cutter rotation (the rotational speed), rpm; z – teeth quantity of a mill.
Floor-to-floor time, min, is calculated by formula

$$t_f = m(t_b + t_{au}) + t_{rest} + t_{service},$$

where m – quantity of technological passes, pieces; t_{au} – auxiliary time which is necessary for preparing to cutting, minutes; t_{rest} – time which is necessary for rest per one workpiece, minutes; $t_{service}$ – service time which is necessary for removing chip, oiling, resharpening of the cutting tool per one workpiece, minutes.

Table 1

Calculation of calculated floor-to-floor time for complex part

№ op.	№ mach. pass	Cutting tool	Depth of cut *t*, mm	Feed *s*, mmpr	Cutting speed *v*, mpm	Diameter d, mm	Frequency of rotation n, rpm	Length L, mm	Base time t_b, min	Floor-to-floor time, min	Preparatory works $T_{p.f.}$, min	Calculated floor-to-floor time, $t_{c.\,f.\,f}$, min
0												
Op. 1, lathe 16K20	1	Mount a blank in an universal 3-jaw chuck, 0.15 min								2.38	25	2.53
	2	Cutter T15K6	3	0.4	150	210	250	35	0.35			
	3	Cutter T15K6	2.5	0.4	150	210	250	8	0.08			
	4	Boring Cutter T15K6	2	0.3	130	120	350	9	0.09			
	5	Boring Cutter T15K6	2.2	0.3	130	138	350	26	0.25			
	6	Boring Cutter T15K6	0.3	0.1	350	139.5	800	26	0.33			
	7	Boring Cutter T15K6	1.6	0.1	350	139.5	800	1.6	0.018			
	8	Boring Cutter T15K6	0.5	0.1	350	139.5	800	0.5	0.006			
	9	Take off the blank, 0.1 min										
Op. 2, lathe 16K20	1	Mount a blank in an universal 3-jaw chuck, 0.15 min								2.23	25	2.38
	2	Cutter T15K6	3	0.4	150	172	300	25	0.23			
	3	Cutter T15K6	2.5	0.4	150	172	300	27	0.225			
	4	Cutter T15K6	0.3	0.1	350	170.5	630	27	0.43			
	5	Cutter T15K6	0.5	0.1	350	170.5	630	0.5	0.09			
	6	Take off the blank, 0.1 min										
Op. 3, drilling machine 2118	1	Mount a jig box on the blank, place on the table of the drilling machine, 0.2 min								1.9	10	1.96
	2	Drill P6M5	6.5	0.2	35	13	800	12	0.08			
	3	Drill P6M5	6.5	0.2	35	13	800	12	0.08			
	4	Drill P6M5	6.5	0.2	35	13	800	12	0.08			
	5	Drill P6M5	6.5	0.2	35	13	800	12	0.08			
	6	Drill P6M5	6.5	0.2	35	13	800	12	0.08			
	7	Drill P6M5	6.5	0.2	35	13	800	12	0.08			

	8	Take off the jig box from the blank, take off the blank , 0.2 min										
4	1	File 9XC	0.5	---	---	---	---	---	0.5	1.2	0	1.2
Op.5 cylindr.. grinder 3M151	1	Mount a blank on a self-centering mandrel, 0.05 min										
	2	Grinding wheel	0.05 0.01	6	35 mps 20	250 170	3000 40	27×6 ×2	1.35	1.45	25	1.6
	3	Take off the blank, 0.05 min										
Op.. 6 internal.. grinder 33K228B	1	Mount a blank in a collet chuck, 0.05 min										
	2	Grinding wheel	0.02 0.01	2	35 mps 20	70 140	1000 0 50	26×6 ×2	3.12	3.13	25	3.28
	3	Take off the blank, 0.05 min										
7	1	File 9XC	0.5	---	---	---	---	---	0.5	1.2	0	1.2
8	1	---	---	---	---	---	---	---	---	0.1	0	0.1
9	1									2	5	2.03
	Calculated floor-to-floor time for the whole manufacturing process, T_{cf}											16.28

6. Determine the batch size for the complex part

$$n = N\times f/ F = 10000\times5/303 = 165 \text{ pieces,}$$

where n – the batch size, pieces; N – the annual program for manufacturing all parts of all groups, piece; F – a number of working days in a year (303), days; f – a number of days of a stock for parts storage before assembling, days (2-5).

7. Determine calculated floor-to-floor time for each operation, write down the results of calculation in Table 1.

8. Determine calculated floor-to-floor time for the whole manufacturing process, write down the results of calculation in Tables 1 and 2 (column 10);

Table 2

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

№ of part	Weight of part, kg	Reduction factor on weight, $K_{w\,j}$	Annual production program, N_j, pieces	Reduction factor on seriality, $K_{s\,j}$	Average grade of tolerance and accuracy factor $K_{a\,j}$	Average surface roughness, Ra, microns, and roughness factor $K_{Ra\,j}$	Reduction factor on complexity, $K_{c\,j}$	Total reduction factor, $K_{r\,j}$	Labour input of manufacturing one part *j*, $T_{c.f.\,j}$, minutes	Labour input of annual program 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	**16.28**	Calculation is not required
1	7	1.25	500	1.12	11→1.0	10→ 0.9	0.66	**0.924**	15.05	125.2
2	5	1	1000	1	8→1.5	2.5→ 1.1	1	1	16.28	271.3
3	7	1.25	500	1.12	8→1.5	2.5→ 1.1	1	1.4	22.79	189.9
4	5	1	1000	1	7→2.0	2.5→ 1.4	1.7	1.7	27.68	461.3
5	7	1.25	500	1.12	7→2.0	2.5→ 1.4	1.7	2.38	38.75	322.9
6	2	0.54	2000	0.97	11→1.0	10→ 0.9	0.66	0.35	5.7	189.9
7	7	1.25	500	1.12	11→1.0	10→ 0,9	0.66	0.924	15.04	125.36
…	…	…	…	…	…	…	…	…	…	…
j	7	1.25	500	1.12	8→1.5	2.5→ 1.1	1	1.4	22.79	189.9
		Total:	10,000				**Total:** $T_{\Sigma N\,c.f.} = \Sigma T_{N\,c.f.\,j}$			**50620 hrs.**

Notice: part № 0 is the complex part and it is not required to calculate labour input of the annual program to process this part.

9. Calculate reduction factors for all parts of the considered group, write down the results of calculation in Table 1;
10. Labour input is determined through *the reduction coefficient* calculated for each part,

$$T_i = T_{repr.} \times K_{red_i}\,, \qquad (1)$$

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

The reduction coefficient is determined in accordance with the formula

$$K_{red_i} = K_{w_i} \times K_{s_i} \times K_{c_i} \times K_{m_i}\,, \qquad (2)$$

where: $K_{w\ i}$ – 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); $K_{s\ i}$ – the reduction coefficient of seriality (the more the production program, the more possibility of applying special attachments which reduce time for part installation); $K_{c.i}$ – the reduction coefficient of complexity; $K_{m.i}$ – 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:

$$K_{w_i} = \sqrt[3]{\frac{W_i^2}{W_{rep}^2}}\,, \tag{3}$$

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 program of the part-representative to the annual production program of the considered *i* part (N_{rep}/N_i):

$$K_{s\,i} = (N_{rep} / N_i)^{\alpha}\,, \tag{4}$$

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:

$$K_c = \frac{K_{a\_i} \times K_{r\_i}}{K_{a\_rep} \times K_{r\_rep}}. \qquad (5)$$

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 3. 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 4. 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 program is calculated for each part in the group: $T_{Ni} = T_i \times N_i$. Labour intensity of machining the annual program of all parts in the group is calculated as the sum of labour intensity of the annual program 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 program 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 $T_{gen.}$.

In our example we suppose that processing of parts of other groups will be carried out in other shops

$T_{gen.} = \sum T_{\sum Ni}$. = 50620 hrs (see Table 2)

11. Define operations in which the same model of the machine tool is used in accordance with the technological process to machine the complex part. Calculate total calculated floor-to-floor time to process one complex part for each model of the machine tool, write down the results of calculation in Table 5;

For example:

Table 5

Calculation of labour input for small-scale manufacture

Model of machine tool	Number (name) of a part	Numbers of operations (j), №	Summing-up calculated floor-to-floor time $t_{c\ f}$ of operations using the same model of the machine tool $\Sigma t_{c\ f\ j}$, minutes
1	2	3	4
16K20	complex part	1, 2	2.53+2.38=4.91
2118	complex part	3	1.96
3M151	complex part	5	1.6
3K228B	complex part	6	3.28
Metal worker's bench	complex part	4, 7	1.2+1.2=2.4
Washing machine	complex part	8	0.1
Workplace of quality inspector	complex part	9	2.03
Labour input of machining one part, $T_{c.f.}$, minutes			$T_{c.f.\ complex} = 16.28$

12. Calculate the level of equipment use $\alpha_{m\text{-}t}$ for each model of the machine tool;

For example:

$\alpha_{16K20} = \Sigma t_{c\ f\ 16K20} / T_{c.f.\ complex} = 4.91/16.28 = 0.302;$
$\alpha_{2118} = \Sigma t_{c\ f\ 2118} / T_{c.f.\ complex} = 1.96/16.28 = 0.115;$
$\alpha_{3M151} = \Sigma t_{c\ f\ 3M151} / T_{c.f.\ complex} = 1.6/16.28 = 0.10;$
$\alpha_{3K228B} = \Sigma t_{c\ f\ 3K228B} / T_{c.f.\ complex} = 3.28/16.28 = 0.20;$
$\alpha_{bench} = \Sigma t_{c\ f\ bench} / T_{c.f.\ complex} = 2.4/16.28 = 0.147;$
$\alpha_{washing\ machine} = \Sigma t_{c\ f\ washing\ machine} / T_{c.f.\ complex} = 0.1/16.28 = 0.006;$
$\alpha_{quality\ inspector} = \Sigma t_{c\ f\ quality\ inspector} / T_{c.f.\ complex} = 2.03/16.28 = 0.125.$

Verification:

$\Sigma\alpha_{m\text{-}t}$ = 0.302+0.115+0.1+0.2+0.147+0.006+0.125 = 0.995 ≈ 1.

13. Calculate the required quantity of the equipment of each model of the machine tool to process the annual program of all parts in the shop (calculated $C_{c\ m\text{-}t}$ and accepted $C_{ac\ m\text{-}t}$ quantity, taking into account the actual time arrangement at specified quantity of working shifts $F_{r\ sh}$). 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).

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

For other types of the equipment (machine tool or MT) the actual annual time arrangement (in less detail) is shown in Table 6.

Table 6

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

For example: for 2 shifts a day $F_{r\,2}$= 4015 hrs and for total labour input $T_{\Sigma N\ c.f.}$ = = 50620 hrs (Table 2) total calculated quantity of machine tools:

$C_{c\ m\text{-}t} = T_{\Sigma N\ c.f.} / F_{r\,2}$= 50620/4015 = 12.607 pieces.

$C_{c\ m\text{-}t} = T_{\Sigma N\ c.f.} / F_{r\ 2} = 50620/4015 = 12.607$ pieces.

$C_{c\ 16K20} = C_{c\ m\text{-}t} \times \alpha_{16K20} = 12.607 \times 0.302 = 3.807$ pieces; $C_{ac\ 16K20} = 4$ pieces.

$C_{c\ 2118} = C_{c\ m\text{-}t} \times \alpha_{2118} = 12.607 \times 0.115 = 1.449$ pieces; $C_{ac\ 2118} = 2$ pieces.

$C_{c\ 3M151} = C_{c\ m\text{-}t} \times \alpha_{3M151} = 12.607 \times 0.1 = 1.26$ pieces; $C_{ac\ 3M151} = 2$ pieces.

$C_{c\ 3K228B} = C_{c\ m\text{-}t} \times \alpha_{3K228B} = 12.607 \times 0.2 = 2.52$ pieces; $C_{ac\ 3K228B} = 3$ pieces.

$C_{c\ bench} = C_{c\ m\text{-}t} \times \alpha_{bench} = 12.607 \times 0.147 = 1.85$ pieces; $C_{ac\ bench} = 2$ pieces.

$C_{c\ washing\ machine} = C_{c\ m\text{-}t} \times \alpha_{washing\ machine} = 12.607 \times 0.006 = 0.075$ pieces; $C_{ac\ washing\ machine} = 1$ piece.

$C_{c\ quality\ inspector\ point} = C_{c\ m\text{-}t} \times \alpha_{quality\ inspector\ point} = 12.607 \times 0.125 = 1.575$ pieces; $C_{ac\ inspector\ point} = 2$ pieces.

The total quantity of accepted machine tools is calculated in such a way:

$C_{ac\ tot} = \Sigma C_{ac\ m\text{-}t} = 4 + 2 + 2 + 3 + 2 + 1 + 2 = 16$ pieces.

14. Calculate the required production floor space for the shop to place the accepted quantity of machine tools;

The total production floor space

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

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.

In our example we suppose that specific production area is the same for all machine tools and we deal with medium size machine tools and a small shop (manufacturing division, or cell, or site), consequently the specific production area is maximum in the considered group of medium size machine tools:

$$S_m = C_{ac\ tot} \times f = 16 \times 20 = 320\ m^2.$$

15. Define the optimum arrangement of the production equipment in the shop and calculate the optimum width, and then length of the production department according to the required production floor space;

In our example equipment arrangement will be parallel to aisle way (access) (see Fig. 8).

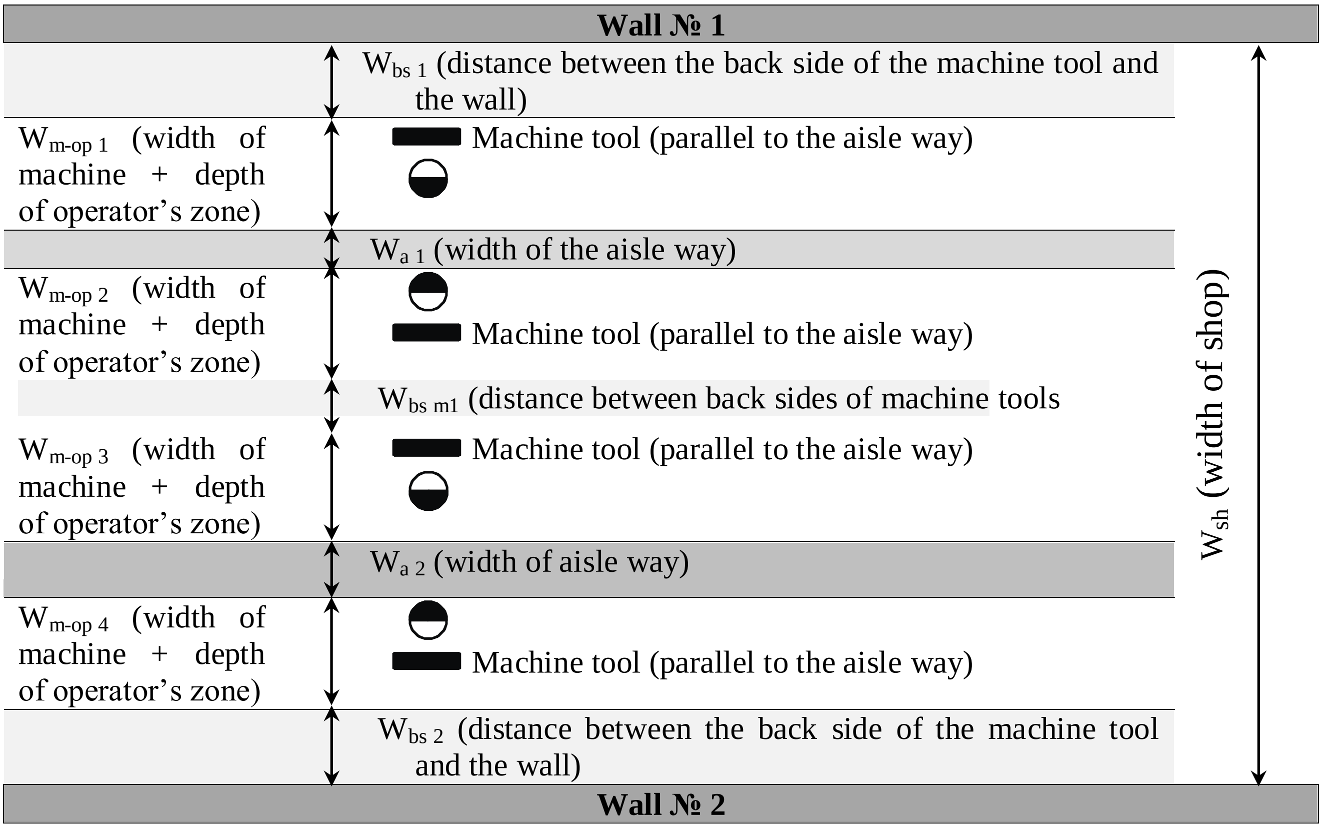


Fig. 8. Scheme of machine tool arrangement (for calculating the shop width)

The width of the shop is calculated:

$W_{sh} = W_{bs\,1} + W_{m\text{-}op\,1} + W_{a\,1} + W_{m\text{-}op\,2} + W_{bs\,m1} + W_{m\text{-}op\,3} + W_{a\,2} + W_{m\text{-}op\,4} + W_{bs\,2}$,

where $W_{bs\,1}$ – distance between the back side of the machine tool and the wall; $W_{m\text{-}op\,1}$ – total width of the machine & depth of operator's zone; $W_{a\,1}$ – width of the aisle way; $W_{m\text{-}op\,2}$ – total width of the machine & depth of operator's zone; $W_{bs\,m1}$ – distance between the back sides of the machine tools; $W_{m\text{-}op\,3}$ – total width of the machine & depth of operator's zone; $W_{a\,2}$ – width of the aisle way; $W_{m\text{-}op\,4}$ – total width of the machine & depth of operator's zone; $W_{bs\,1}$ – distance between the back side of the machine tool and the wall.

The total width of the machine & depth of operator's zone depend on the model of the machine tool, it is necessary to determine them by using reference books. On average for medium equipment the total width of machine & depth operator's zone is equal to 1500+800=2300 mm, where 1500 mm is the width of medium machine tools, 800mm is the depth of operator's zone. $W_{m\text{-}op\,1} = W_{m\text{-}op\,2} = W_{m\text{-}op\,3} = W_{m\text{-}op\,4} = 2300$ mm.

The width of shop aisle ways depends on the width of a vehicle or the width of a transported cargo. For small shop traffic is used in one-way

$$W_a = B + 1400,$$

where W_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. On average for medium production the width of a vehicle is equal to 1500 mm. On average the width of a shop aisle way $W_{a\,1} = W_{a\,2} = 2900$ mm.

Distance between the back side of the machine tool and the wall $W_{bs\,1}$ depends on the model of the machine tool, it is necessary to determine them by using reference books. On average for medium production $W_{bs\,1}$ = 500 mm (see Table 11.1 of the teaching aid [1]).

Distance between the back sides of the machine tools $W_{bs\,m1}$ depends on the model of the machine tool, it is necessary to determine them by using reference books. On average for medium equipment $W_{bs\,m1}$ = 800 mm (see Table 11.1 of the teaching aid [1]).

We calculate the width of the shop:

$W_{sh} = W_{bs\,1} + W_{m\text{-}op\,1} + W_{a\,1} + W_{m\text{-}op\,2} + W_{bs\,m1} + W_{m\text{-}op\,3} + W_{a\,2} + W_{m\text{-}op\,4} + W_{bs\,2}$ = = 500 + 2300 + 2900 + 2300 + 800 + 2300 + 2900 + 2300+ 500 = 16800 mm = = 16.8 m.

The length of the machining shop is calculated $L = S_m / W_{sh} = 320/16.8 = 19$ m, where S_m – the total production floor space, m^2.

16. Make an equipment layout in accordance with the accepted arrangement and final calculation of the width and length of the shop.
    In our example auxiliary services are not placed on the shop floor space. Auxiliary services can be placed at the beginning and at the end of the shop. In this case the width of the shop will be the same, but the length of the shop will be larger.
    This variant is used for insufficient amount of floor space for auxiliary services (only places for a foreman, tool-grinding department, tool storage room, storehouse for blanks, quality inspector point and two rest rooms (for men and women). Other components of the auxiliary system are placed in an annexe.
17. To calculate the total area of a building it is necessary to multiply the floor space S_m 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.
    The width of the manufacturing building in this case will be 4-9 m larger.
18. Specify the scale in which the layout will be carried out so that the maximum size of the shop floor can be fitted into the sheet. Besides, on the sheet with the future layout there should be some place reserved for a frame and title block.
19. Draw the shop floor contours and basic structural elements in accordance with the accepted scale. Make auxiliary services layout in accordance with the accepted arrangement.
20. On a separate sheet of Whatman paper draw the contours of each object which are on the old shop floor layout to the accepted scale. Cut out a template, write the name of the object on it.
21. Put the cut templates on the sheet with scale shop floor contours and find the optimum variant from the view point of filling the minimum area without breaking design norms. It will be better to place the equipment in order of performing the part-representative master schedule.
    The first operation is usually performed on the left of the entrance (as a rule, the storehouse for blank is located there) and closer to a longitudinal wall.

After determining the optimum variant of the equipment arrangement, the templates are outlined by a pencil with a thin line. The equipment contours are thoroughly outlined after finishing the whole shop floor layout.

Write numbers on the object images which will correspond to the object names in the specification attached to the layout (these numbers, as a rule, will not coincide with those written on the templates).

22. Specify the numbers on object images in accordance with the count (beginning with 1), first start from the top from left to right, and then one line below from left to right, etc. If the considered object has already been specified on the layout, it is given the same number and the specification will contain the information about the quantity of such objects on the shop floor layout.
23. Make the final layout of auxiliary services in accordance with the accepted arrangement, and final calculation of the width and length of the shop or building.
24. Specify the sizes of the shop floor, the width of the entrance door and emergency exits, overall dimensions of all departments (for example, the tool-grinding department, the training department, etc.), the distance between machine tools and from walls to machine tools, the width of the aisle ways on the layout.
25. Fill in the specification.

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Educational Edition

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ПРОЕКТИРОВАНИЕ МЕХАНОСБОРОЧНЫХ ЦЕХОВ

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