National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute»

Educational and Research Institute щf Mechanical Engineering

Department of Manufacturing Engineering

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______________ Oleksandr OKHRIMENKO

“___”_____________2025

Diploma project

for a bachelor's degree
according to the educational and professional program

«Manufacturing Engineering»
in the specialty 131 «Applied mechanics»

on the topic: Technological preparation of a manufacturing process to produce a part “Clamp"

Developed by:
the student of 4th year of study, group MT-13

Student: Elmiry Ahmed Maher Ahmed Mahmoud

(signature)

Academic supervisor: Maksym Gladskyi, PhD, Associate Professor

(signature)

Reviewer:

(position, academic degree, academic title, surname and initials) (signature)

I certify that in this diploma project
there are no borrowings from the works
of other authors without appropriate references.

Student ***Elmiry Ahmed Maher Ahmed Mahmoud***

(signature)

Kyiv – 2025

National Technical University of Ukraine
«Igor Sikorsky Kyiv Polytechnic Institute»

Educational and Research Institute щf Mechanical Engineering

Department of Manufacturing Engineering

Level of higher education – first (bachelor)
Specialty – 131 “Applied Mechanics”
Educational and Professional Program “Manufacturing Engineering”

APPROVED
Head of the department

_____________ Oleksandr OKHRIMENKO

«___»____________2025

ASSIGNMENT

for the diploma project to the student

Elmiry Ahmed Maher Ahmed Mahmoud
(full name)

1. Topic of the diploma project: Technological preparation of a manufacturing process to produce a part “Clamp"

project supervisor Maksym Gladskyi, PhD, Associate Professor,

(full name, academic degree, academic title)

approved by the University Order dated «___» _____202__p. № _______

2. The deadline for the student to submit a diploma project: June 15, 2025

3. Initial data for the project:

- complete the study of the state-of-art of additive technologies;
- complete process planning for Clamp for, annual production volume 2,000 units; Part material steel 30.

4. The content of the explanatory note, a list of tasks to be developed:

1 Study section, 2 Technological part, 3 Design of machine tools, Economic section.

5. A list of graphic and illustrative material: presentation is required, at least of 5 drawings such as detail, workpiece, process example, machine tools.

6. Consultants for chapters of the project

Chapter	Surname, initials, and position of consultant	Issued the task	Accepted the task

7. Issue date of the assignment: April 19, 2025.

CALENDAR PLAN

No	Stages of the diploma project implementation	The deadline for the stages of the diploma project	Notes
1	Study section	May 1, 2025	complete
2	Design of detail and workpiece	May 8, 2025	complete
3	Process planning	May 31, 2025	complete
4	Design of machine tools	June 15, 2025	complete
5	Economic section	June 15, 2025	complete

Student	***Elmiry Ahmed Maher Ahmed Mahmoud***
Supervisor	***Maksym GLADSKYI***

Contents

Introduction

Mechanical engineering is an integral part of industry. The level of development of mechanical engineering is one of the most significant factors in scientific and technological progress and largely determines the advancement and improvement of a country's entire economy. Fundamental transformations in any field are only possible as a result of the creation of more advanced and fundamentally new technologies.

The development and improvement of manufacturing technology today is closely linked to automation, the creation of production complexes and work areas using CNC machines, the widespread use of computing technology, and the application of CNC equipment. All of this forms the foundation for the creation of automated production, enables the optimization of technological processes, and the development of flexible automatic systems. It is crucial to manufacture machinery efficiently, with minimal cost, and within deadlines, using modern high-performance equipment, tools, and automation systems.

The reliability and quality of manufactured machines and parts depend largely on the developed manufacturing technology. By improving the manufacturability of a design, it becomes possible to increase production output using the same resources and to reduce manufacturing costs.

Engineering and technical personnel actively participate in solving these tasks on the production floor. This diploma project aims to solve specific problems in the field of process improvement and the enhancement of the technical and economic efficiency of part manufacturing.

The purpose of the diploma project is to consolidate and deepen practical knowledge in solving typical technological problems and to acquire practical skills in addressing challenges encountered during the development of manufacturing processes and the design of tooling. The project includes:

- Describing the design of the part, analyzing its manufacturability, and identifying technical requirements;
- Properly selecting the workpiece and determining its dimensions and machining allowances;
- Independently developing technological processes for manufacturing the part and assigning reference bases in the context of an automated production process;
- Rationally selecting machine tools, technological fixtures, cutting and measuring instruments;
- Calculating cutting parameters and time norms.

The diploma project includes the following production indicators:

- Annual production volume: 2,000 units;
- Part material: Steel 30L.

1. General issues of mechanical engineering

1.1. Additive technologies, or 3D printing

We live in a time of rapid development of industrial technologies, which in itself is only part of the general explosive growth of the technical capabilities of mankind. In this context, many examples can be cited at once, such as the development of artificial intelligence technologies, the transition to renewable energy sources, the development of nanotechnologies and the latest polymer and composite materials. Products made of carbon fiber no longer surprise anyone. More and more often, people say that we live in the era of the fourth industrial revolution.

Additive technologies or layer-by-layer synthesis technologies, 3D printing is today one of the most dynamic areas of “digital” production. They allow to significantly accelerate the implementation of research and development work and solve the problems of production preparation, product manufacturing. Technologies can significantly increase the profitability of the production of a single unit of product and reduce barriers to the organization of production. 3D printing is capable of revolutionizing many areas of life. In terms of development dynamics, the additive technologies market is ahead of all other industries.

Most modern technologies are based on the substantive approach production: excess material is removed from the resulting workpiece, providing workpiece of a given shape (drilling, milling, cutting, grinding, turning, and so on) Instead, additive manufacturing involves building from scratch sequentially created by layers of material that reflect the contour boundaries of the model, until the finished product is received.

The essence of the process is to layer the CAD model into sections and then build up the product directly in the printing device, repeating the sections of the model. Add - add in English. Adding layer by layer to create a part is what additive technologies are. The main advantage of this group of technologies is the ability to create geometric forms of virtually unlimited complexity. Typical layer thickness is 100 microns (250 DPI).

1.2. History of the industry

In fact, the type of additive manufacturing technology that we now call “lamination” has been around for over 100 years. Back in the days of the Wright brothers, the complex three-dimensional parts of the first airplanes, made almost entirely of plywood, were created by successively gluing layers of plywood together, each with its own shape—an extension of the previous layer.

Although 3D printers have only become widely talked about in recent years, the history of the development of three-dimensional printing, in its modern sense, dates back about 30 years: the first application was recorded in the 1980s. In 1984, American Charles Hall developed stereolithography technology and created the first 3D printer, the Stereolithography Apparatus. He defined the term “stereolithography” as “a system for generating three-dimensional objects through layer-by-layer formation.” In 1986, he received a patent for his invention and founded the company 3D Systems. In 1988, they entered the market with the first serial model, the SLA-250, which was created based on Charles Hall’s original printer. Currently, this company is one of the world leaders in the field of additive technologies.

While 3D copying technologies had become widely popular by the end of 1988, new technologies emerged: Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS). Fused Deposition Modeling technology was invented by Scott Crump in 1988. The following year, he founded Stratasys and established industrial production of machines. In 1992, the company sold its first machine, the "3D Modeler". In the same year, DTM launched a machine using Selective Laser Sintering (SLS) technology. In 1993, another 3D printing technology was invented and patented at the Massachusetts Institute of Technology (MIT). It was similar to the inkjet printing technology used in 2D printers. In 1995. ZCorporation (acquired by 3D Systems in 2013) received a patent from the Massachusetts Institute of Technology for the use of the technology and began producing 3D printers based on 3DP technology.

The popular (though not widely used among specialists) term "3D printing" did not appear immediately. The technology was initially mostly referred to as "rapid prototyping". It was only in 1995, thanks to two students from the Massachusetts Institute of Technology - Jim Bradt and Tim Anderson, who created a new technology called "Three-dimensional Printing Technology" and with which the ZCorporation company soon entered the market, that the name "3D printing" quickly became dominant.

According to ASTM (American Society for Testing and Materials) standards, it is recommended to use two main terms — Additive Fabrication (AF) and Additive Manufacturing (AM), as well as synonyms — additive processes, additive techniques, additive layer manufacturing, layer manufacturing and freeform fabrication, which can be correctly translated as “additive technologies”. It is recommended to remove the term Rapid Prototyping from circulation as one that has lost the meaning of understanding modern additive technologies.

1.3. Main types of modern 3D printing and its uses

1.3.1. Using additive technologies in prototyping

The main technologies for manufacturing prototypes include mechanical processing; photopolymerization; stereolithography; laser sintering of powder materials; layer-by-layer application of molten polymer filament; bonding (lamination) of layers; casting in elastic silicone molds; low-pressure casting; creation of solid objects using printers; manufacturing models from foamed plastics; casting prototypes in trial molds. Almost all of the listed technologies can be used to obtain a prototype and model with a high-quality appearance.

The task of rapid prototyping, that is obtaining a prototype of a product in the shortest possible time, remains one of the main tasks of the practical application of AM technologies. In this case, the concept of "prototype" is quite broad. At the stage of performing scientific research work, it is necessary to quickly obtain a prototype of the product. At this stage, it is important to work out the geometry of the part, assess ergonomic qualities, check the assembly and correctness of layout solutions. Therefore, "rapid" manufacturing of a part using "bypass technology" allows you to significantly reduce the time for product development. A prototype is also understood as a model, sometimes large-scale, intended for any tests (for example, hydro- or aerodynamic) or preliminary verification of functionality (for example, case parts of devices, radio stations, medical or household appliances). A large number of prototypes are built as search design models with various nuances in configuration, color scheme, and so on

Typically, the process of creating a new product from the idea to the SOP (Start of Production) point is iterative and involves the creation of prototypes or prototypes of several series "A", "B", "C" and more, depending on the complexity of the development object. At the final stage (pre-production) product samples are usually manufactured using special equipment designed for industrial production conditions. However, for the early stages of development of series "A", "B", when the image of the product is not finally defined, the use of expensive equipment is extremely costly. As a rule, in the process of testing and testing, the product configuration undergoes significant changes, and the equipment manufactured for the production of prototypes turns out to be unsuitable for serial production. One of the most important advantages of using AM technologies is that they allow you to obtain functional prototypes (prototypes) without the use of expensive technological equipment. For example, an internal combustion engine cylinder block, which is quite suitable for conducting full-fledged engine tests, can be made by rapid prototyping, without the manufacture of wooden or metal models and molds. Full-fledged foundry equipment is manufactured after the completion of tests, adjustment of design documentation and thorough technological preparation. And if the issue of the use of additive technologies in industrial production remains debatable, then in terms of R&D and R&D they have already proven their very high efficiency.

AM technologies as “rapid prototyping” technologies are used mainly at the initial stage of projects – to reproduce the geometric image of the product. At this stage, surface texture, strength and other material properties are usually neglected, choosing from the available model materials the most suitable for visualization purposes. Sometimes the properties of the model material allow for functional testing of the prototype.

Inexpensive 3D printers are most often used for prototyping purposes. costing between 20-100 thousand euros. For the production of large-sized models and models with increased requirements for surface quality and strength, more expensive AM technologies (SLA, SLS) and professional machines costing € 150-900 thousand and more are used.

1.3.2 . Use of additive technologies in foundry production

The use of additive technologies in foundry production allows you to "grow" foundry models and molds that could not be produced by traditional methods, and also significantly reduces the time for manufacturing model equipment. The use of molds and models obtained using additive technologies in the vacuum casting process has made it possible to reduce the time for manufacturing pilot, prototypes and, in some cases, serial products - by dozens of times.

The transition to digital product description - CAD and the subsequent emergence of additive technologies have caused radical changes in foundry production, which was especially evident in high-tech industries - aviation and aerospace, nuclear industry, medicine and instrument making, in industries where small-scale, one-off production is typical.

A significant part of castings that do not have special requirements for casting accuracy or structure can be obtained as finished products within 3-4 days, taking into account the preparatory and final time: direct growing of a wax model or Quick-cast model (1 day); molding + drying of the mold (1 day); hardening of the mold and actual casting (1 day).

The molds are created without bulky and expensive equipment in a fully automated process, entirely based on CAD data, using the layer-by-layer method (repeatedly applying layers of 300 micrometer-thick quartz sand, which are selectively glued together with a bonding component using the system's print head). Compared to homemade sand molds, these parts have a much smoother surface. In addition to the time factor, there are several other factors that reduce costs and speak in favor of using layer-by-layer printing technology. In terms of overall costs, up to the series volume, 3D printing is significantly cheaper than traditional methods due to the absence of tooling costs. The smaller the batch, the greater the savings when using the technology.

Investment casting

To obtain metal castings in the manufacture of small series or prototypes, molds printed on a 3D printer are successfully used. Foundry wax is poured into these molds, then the wax scraps are used to manufacture ceramic molds in the process of casting from melted models. The second option is to obtain the model directly; in this case, the following materials can be used in the model composition: lignite wax, rosin, block polystyrene, expanded polystyrene, polyethylene wax, urea, ethyl cellulose.

Casting into the ground

This is a classic, well-known metal casting technology. It differs from investment casting in that it is somewhat less accurate, but it is much cheaper. Typically, this technology is used when it is necessary to obtain fairly large castings from both non-ferrous and ferrous metals. A 3D printer allows you to quickly and with excellent quality obtain a model for sand molding and a set of liners if necessary. After coating with paint that protects the surface from scratches, the model can be used for molding up to several dozen times without deteriorating the quality of the casting. As a rule, one master model grown on a 3D printer is quite enough to obtain a small series of castings.

Shell casting

An accurate model of the product and a sprue system are made. The model is immersed in a liquid suspension based on a binder and refractory filler. The suspension is applied to the model block and it is sprinkled, so from 6 to 10 layers are applied. Drying of each layer takes at least half an hour, to speed up the process, special drying cabinets are used, into which ammonia gas is pumped. Model material is melted from the resulting shell: in water, in model material, by firing, high-pressure steam. After drying and melting, the block is calcined at a temperature of approximately 1000 ° C to remove substances capable of gas formation from the shell form. After that, the shells are sent for pouring.

1.3.3. Use of additive technologies in direct printing of products

1.3.3.1. Direct printing of non-metallic products

Photopolymer printing, or stereolithography (SLA)

The essence of the method is to project a section of the model onto a polymer liquid, after which the polymer solidifies where it was illuminated. This operation is then repeated layer by layer: the 3D printer head is raised a fraction of a millimeter and the next projection is illuminated. The spread of polymers with different physical properties allows you to print hard, soft and even flexible models. The material for printing is photopolymer resin.

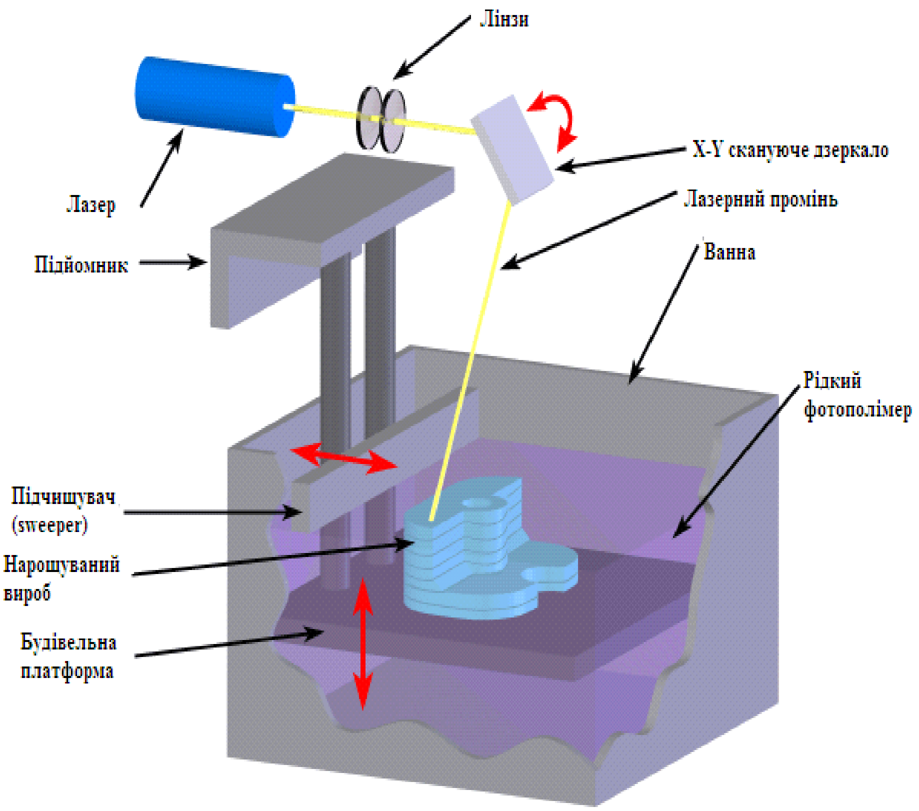


Figure 1.1 SLA printer operation diagram technology

Printing with molten material, or extrusion (fused deposition modeling – FDM)

Basically, printing is done by heating the material and squeezing it onto the surface. The method is similar to the principle of a glue gun, where a plastic rod is fed from one end of the device, and at the other end it is heated to a fluid state and squeezed out. The material for printing is thermoplastics (PLA, ABS, PVA, HIPS, and so on), low-melting metals and alloys.

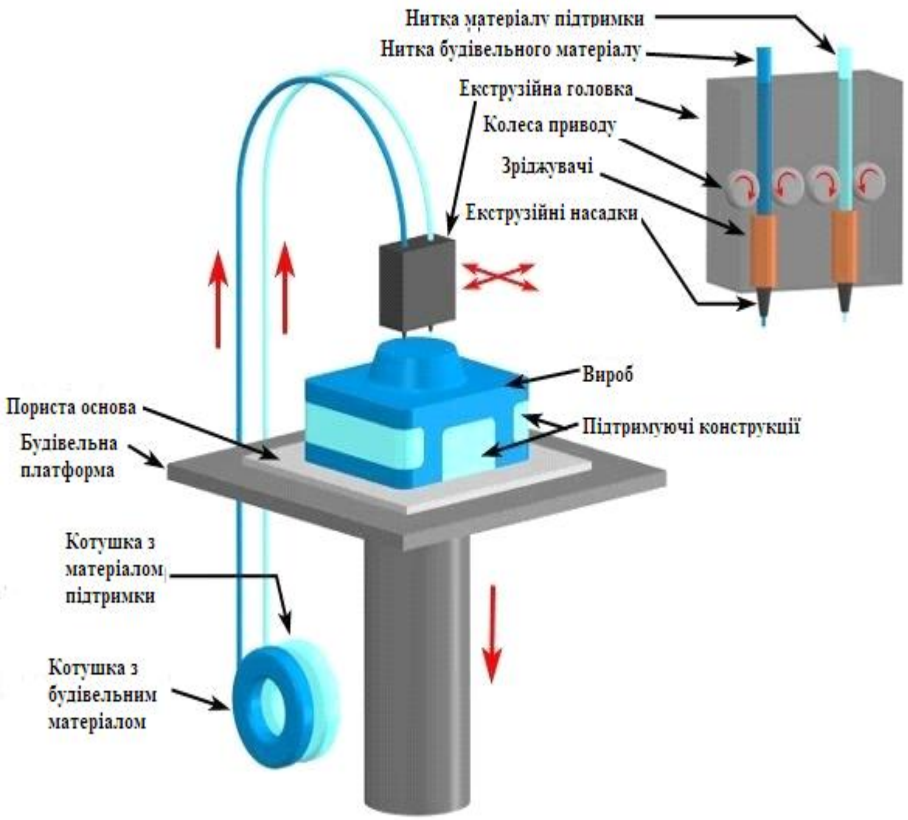


Figure 1.2. FDM printer operation diagram technology

Digital light processing (DLP)

Analogue of SLA technology. Unlike traditional stereolithography technology, which uses a scanning ultraviolet laser to solidify a liquid material, a DLP printer works on a similar principle, but uses a DLP projector that affects each layer. As soon as the first layer solidifies on the platform, the platform is lowered a little deeper into the resin tank, and the projector illuminates a new image to solidify the next layer. The printing material is liquid resin.

Multijet modeling (MJM) technology

The MJM 3D printing technology is based on the layer-by-layer sectioning of the CAD file into horizontal layers, which are sequentially sent to the 3D printer. Each layer is formed by a print head, which releases either molten (temperature about 80 °C) photopolymer or molten wax onto a horizontal moving platform through groups of nozzles. The photopolymer or wax melts in the material supply system before entering the print head. If 3D printing is performed with photopolymer, then after printing each layer, the platform on which the layer is grown moves behind the print head under an ultraviolet lamp. The flash of the ultraviolet lamp causes a reaction of the photopolymer, as a result of which the material hardens. After that, the platform moves back under the print head and the layer formation cycle is repeated. The material for printing is photopolymer resin, acrylic plastic, casting wax.

1.3.3.2. Direct printing of metal products

3D printing of parts directly from metals is an extremely important and promising direction in the development of mechanical engineering technologies in general. It is the metal part that is the “real” product, not just a model, not a mockup, not a “prototype”. It is the final product with the maximum added value.

There are two main methods for printing parts directly from metal - additive fabrication (AF) and direct metal deposition (DMD).

The first method is as follows . First, a layer is formed, for example, a dose of powder material is poured onto the working platform and the powder is leveled with a roller or “knife”, thus creating an even layer of material of a certain thickness; then the powder in the formed layer is selectively (selectively) processed with a laser or other method, bonding the powder particles. This technology is the most developed and most attractive for investment. It is with printers working on this technology that such “monsters” of mechanical engineering as Boeing , Airbus , General Electric , and so on Therefore, let's analyze this method in more detail.

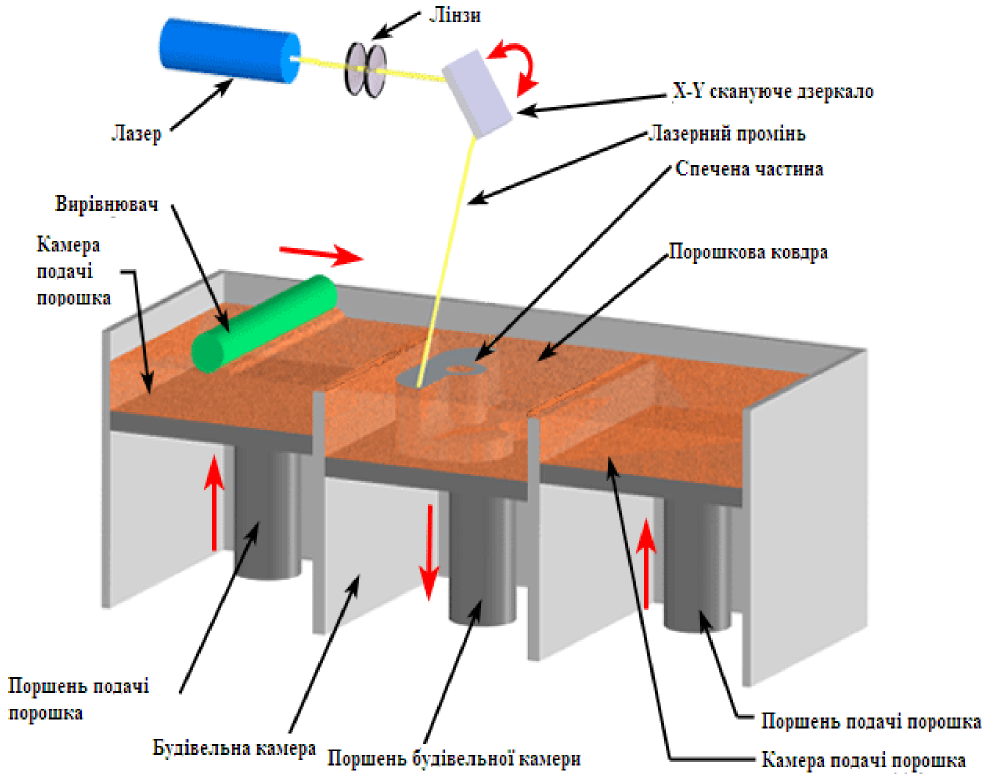
Currently, two main technologies have been created using this method – SLS and computers:

Selective Laser Sintering (SLS)

The essence of the “selective laser sintering” (SLS or Selective Laser Sintering) method is to use high-power laser beams (usually carbon) to partially melt, or “sinter” the consumable material into a single whole. Before use, the consumable material is crushed to a powder consistency using ball mills. The minimum particle size can reach two microns.

Various polymers can be used as the material, or, most attractively, metals and metal alloys with a high melting point. Unlike standard extrusion printing (FDM), the technology allows sintering a homogeneous material without binder additives. Thus, there is no need for heat treatment, and the models themselves after printing have high strength, approaching that of cast samples. Like other 3D printing technologies, laser sintering creates models layer by layer. The process is similar to laser stereolithography: in the case of stereolithography printers, models are immersed in a liquid photopolymer resin to a depth corresponding to the thickness of one layer, followed by "drawing out" a new layer with a laser. During laser sintering, a layer of powder is applied to the model with a thickness of one layer, in which the contour is drawn, and the high temperature allows the powder to partially melt in places where the beam touches the particles, each other and with the previous layer. In both cases, the model is surrounded by unused material. In the case of powder, this point is important: the powder serves as a support for the subsequent layers of the model. This allows you to avoid printing supports. All unused powder can be collected and reused.

The only significant drawback of this technology is the porosity of the part. However, this drawback can be combated by increasing the laser energy and printing time. Then the working material at the printing point does not just sinter, but melts, creating a homogeneous structure. This approach is called “selective laser melting” (SLM).



SLS printer operation diagram technology

Electron beam melting (EBM)

The pioneer and leader in the production of machines for additive manufacturing using the electron beam melting (EBM) method is the Swedish company Arcam. The company was officially founded in 1997, but the birth of a commercial project was preceded by four years of research conducted in collaboration with scientists from Chalmers University of Technology in Gothenburg.

In fact, EBM is based on the same principle as laser melting technology, except it uses high-power electron beams instead of laser beams.

It is worth highlighting the advantages of this technology over laser melting:

Higher accuracy in the horizontal plane. The trajectory of the electron beam is adjusted by manipulating magnetic fields created by so-called “magnetic mirrors.” This method allows for higher accuracy than manipulating optical mirrors used to control laser beams.

The design of optical mirrors and laser lenses requires the use of expensive materials: depending on the laser power, the surface of the mirrors is coated with silver or gold, and the lenses can be germanium or even diamond. In the case of EBM, relatively inexpensive materials are used to produce electromagnetic components.

In addition, the lack of need to manipulate physical objects allows for a higher beam deflection speed, which, together with the increase in energy, allows for higher performance.

Finally, the electron beam can be scattered when needed, allowing the consumable material to be heated without the additional heating elements typical of laser systems. Heating the material is necessary to achieve higher density patterns and facilitate sintering or melting.

A disadvantage of using electron beams is the presence of X-ray radiation that occurs when metals are bombarded with high-energy electrons (the so-called "bremsstrahlung"), which requires the installation of an absorbing coating around the working chamber.

In general, electron beam melting is somewhat more complex than laser melting, but has a higher production potential. Arcam has achieved widespread success among manufacturers of orthopedic implants and aviation parts. Orthopedic implants made using the EBM method are attractive not only for the strength, lightness and wear resistance of the titanium alloys used, but also for the possibility of creating hollow or porous metal structures. Such architecture resembles the structure of bone tissue and promotes osseointegration, that is, the fusion of bone tissue with the implant in a manner similar to the natural physiological process. As for the aviation and oil and gas industries, electron beam melting allows you to create heat-resistant nozzles and blades for gas turbines, including jet engines. In addition, the method is successfully used to create load-bearing titanium wing elements.

The most popular metal powder compositions on the industrial market are: tool steels, martensitic aging steels, aluminum alloys, pure titanium and its alloys, cobalt and chromium alloys, and heat-resistant steels.

When using the second method , unlike the first, a layer of material is not formed, but the material is fed to a specific place, where energy is supplied at a given moment in time and where the process of forming the part takes place. This method is similar to where a welder introduces material from an electrode into the place where a molten zone is formed due to an electric arc. In essence, this is a “metallized” version of the FDM technology , which was discussed above.

1.4. Economic impact of additive technologies

AF-technologies are the most dynamically developing industry, showing a rapid growth rate [20, 21] . In the early 10s of the 21st century, annual growth in this sector of the economy was estimated at approximately 30% per year. Today, growth rates are estimated to be somewhat more modest, at 15% per year. The global market for AM-technologies at the end of 2017 amounted to about 5.31 billion US dollars. It is predicted that by 2025 it will reach 21.5 billion.

A comparison of sales volumes of 3D printers around the world indicates their rapid growth. Thus, in 2013, slightly less than 100 thousand units were sold, while in 2014, 133 thousand printers were delivered to users worldwide. Data from the annual research reports of Wholers Associates on the 3D printing market state that sales volumes in 2015 amounted to almost 218 thousand. Over two years, sales growth of more than 100% is a very high indicator of active market development, which gives grounds to talk about its further positive prospects.

The level of implementation of additive technologies in real production is considered a real indicator of the economic power of the state. As is known, the US economy is considered the largest in the world, it accounts for 38% of machines working on additive technologies. For comparison, the share of Japan is 9.7%, Germany – 9.4%, China – 8.7%, Russia – 1.4%. It shares 11th place with Turkey and is actually at the initial stage of development of this direction. Today, more than 50% of the market belongs to the most developed countries in the world: the USA and the EU countries. Therefore, the relevance and importance of AF-technologies for the development of our state is beyond doubt.

These new technologies can increase the profitability of a single unit of production by an average of 23% and reduce barriers to production by 90%. Once they became commercially available, they immediately impacted production processes across industries.

The application of additive technologies by economic sector is distributed as follows: 21% - consumer goods and electronics production; 20% - automotive industry; 15% - medicine, including dentistry; 12% - aircraft construction and space industry; 11% - manufacturing of production equipment; 8% - military equipment; 8% - education; 3% - construction and architecture.

Such giants as Boeing, Nike, Adidas, Hewlett Packard, Ford, Coca-Cola, GE and others are actively adapting 3D printing and scanning to their needs. All regulatory documents on additive technologies are currently approved by a special international committee created by the Global Alliance of Rapid Prototyping Associations (GARPA), which includes national associations for AM technologies from 22 countries that are actively developing them.

According to expert estimates, the cost savings from using 3D printing in the production of spare parts for maintenance, repair and operation in the aerospace sector of the global market could amount to up to $3.4 billion. Estimates of the growth and impact of 3D printing are changing rapidly. Industry observers predict that by 2020 the 3D printing market will generate revenue of more than $20 billion. The financial impact of this technology by 2025 is estimated at between $230 and $550 billion per year. The greatest impact will be on the consumer ($100 to $300 billion), on direct manufacturers ($100 to $200 billion), and on the creation of tools and molds ($30 to $50 billion) [22] . The prospects for 3D printing are also indicated by forecasts from the world's leading research and consulting company in the field of information technology, Gartner. According to its estimates, the additive technology market will be worth $14.6 billion in 2019 [22] .

Traditional manufacturing methods like injection molding may be cheaper for large-scale production of polymer products, but additive manufacturing has advantages for small-scale production, allowing for higher production rates and design flexibility, along with increased cost-per-unit. Additionally, desktop 3D printers allow designers and developers to create concept models and prototypes from the comfort of their office.

The apparent simplicity of 3D printing is combined with a very high level of requirements for specialists who must have knowledge in the field of materials science, processing of materials with concentrated energy flows, strength, metrology, and so on In many countries, 3D printing is already being taught in schools. For example, in the USA, Pitsco Education develops programs for teaching schoolchildren of various levels of complexity. The VBD publishing group does the same in India. It is believed that early acquaintance of children with advanced innovations in science and technology contributes to the development of their creative abilities and motivates them to choose engineering and technological areas of activity in the future.

At the same time, personal 3D printing potentially raises problems in the form of large-scale infringement of intellectual property rights by users. According to experts, the economic losses caused by the use of 3D printing to intellectual property will amount to 100 billion US dollars in the near future.

1.5. Scientific, technical and inventive activity

Note that 3D printing is a science-intensive industry. On average, 3D printing companies spend almost 20% of their revenues on research and development. Since the first 3D printing patent was granted, a variety of technologies have been created, using different materials and processes. The demand for each type of 3D printing technology depends on the needs and applications. Therefore, they do not compete directly with each other and cannot infringe on each other's rights to patent technologies. 3D printing companies apply their patented inventions in the industrial segment of the market. These companies include giants such as 3D Systems, DuPont, EOS, Envisiontec, and Stratasys.

The top ten patent holders include: Fujitsu and NEC (mostly with patents from the 1980s and early 1990s); 3D Systems, Boeing, Corp Z, LG Philips LCD, Matsushita Denki Sangyo, Objet Geometries, Samsung (mostly with patents from 2000–2010); and Stratasys, with most of its patents issued in the last five years. 3D Systems leads the list of U.S. patents, in part due to its strategy of acquiring other innovative companies.

Since a patent provides the ability to prohibit the use of the claimed method, guaranteed by current legislation, applicants usually seek to protect an important thematic area for them with broad coverage from possible use by other applicants. This protects a promising area of research and development, and competitors are forced to look for other opportunities to work in this direction.

As for Ukraine, its level of implementation of additive technologies is within the statistical error of research. Ukraine's gap with the leading countries in this field continues to grow, especially if we take into account the coordinated efforts of governments, industry and academic institutions of leading countries aimed at spreading additive manufacturing in industry. The implementation of these technologies is impossible without investments in fundamental and applied research. The experience of other countries shows that such a task cannot be solved without significant government participation and thoughtful financial incentives. The development of this science-intensive industry is the basis of the country's technological security and independence.

1.6. Conclusions

Although additive technologies have entered various fields of activity, they are still far from 100% return. In the modern economy, additive technologies are used for prototyping and distributed manufacturing in architecture, construction, industrial design, automotive, aerospace, military, engineering and medical industries, bioengineering (to create artificial fabrics), clothing and footwear production, jewelry, education, geographic information systems, the food industry and many other areas. According to research, home 3D printers with open source code will allow you to recoup the capital costs of your own purchase due to the cost-effectiveness of household production of items. It should be noted that additive technologies in industrial production serve as a complement to traditional subtractive methods, and are not a complete replacement for the latter. The near future is preparing new areas of application for AF technologies.

The advantages of additive technologies include:

- shortening the technological chain and drastically reducing production waste;
- strong individualization of the product being produced;
- accelerating the implementation of new ideas;
- the possibility of manufacturing highly complex parts;
- relative ease of staff training;
- reduction by an order of magnitude of the production cycle time for piece and small-scale production;
- introduction of fundamentally new approaches to product design, allowing the creation of complex spatial non-disassembled parts, lattice lightweight structures made of metals and polymeric materials, the production of which is impossible using conventional technological methods.

The disadvantages of additive technologies include:

- the quality of powder mixtures, polymers and other materials used in production is not entirely perfect, which does not allow the use of layer-by-layer synthesis for the manufacture of products with high requirements for the percentage of defects;
- polymer materials are toxic and cannot be recycled and reused;
- high cost of equipment and consumables;
- limitations of modern CAD modeling programs in terms of the full implementation of the capabilities of additive technologies;
- the issue of protecting intellectual property from the possibility of unlicensed copying of original products or products prohibited for mass use (weapons) has not been developed;
- lack of uniform international and regional standards for the quality and reliability of printed products, requirements for technological processes and equipment, and safety of consumables.

Today, it can be argued that little will be revealed to an outside observer over time. 3D printers exist as an independent market category, they can already do something, but there is much more they are not yet capable of. However, the process is underway, technologies are developing, general directions of their applications are emerging, market niches exist and are actively growing.

2. Technological section

2.1. Technological control of the drawing

As a result of technological control of the clamp drawing, which was issued as an assignment for the thesis, the following was revealed:

- the drawing indicates all the dimensions necessary for the manufacture of the part;

- the roughness of all surfaces of the part is specified in accordance with ***GOST 2789-73*** ;

- tolerances and deviations of dimensions are given in accordance with ***GOST 25346-89*** and ***GOST 25347-82*** ;

- tolerances of the shape and location of surfaces are specified in accordance with ***GOST 24643-81*** ;

- requirements for the accuracy of manufacturing the surfaces of the part do not always meet the requirements for the roughness of these surfaces.

2.2. Analysis of the functional purpose of the part

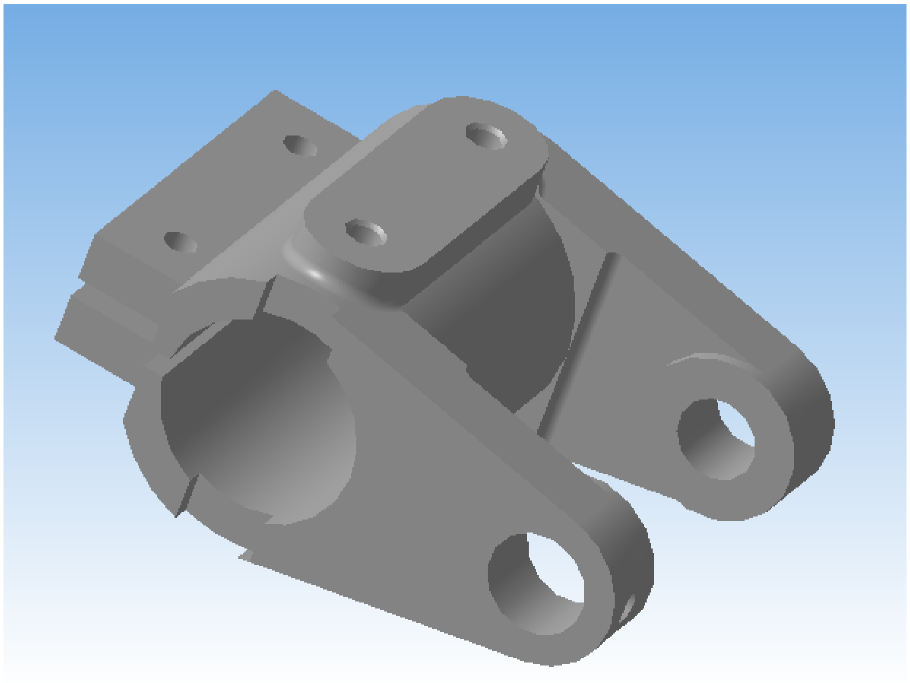


Figure 2.1 Clamp

The lack of data on the product's intended purpose makes it difficult to accurately determine the purpose of the part. However, considering its configuration and dimensions, it can be assumed that the clamp is a medium-duty mechanical engineering part.

A clamp refers to small parts of complex shape, or to body parts and can be used for fastening and sealing hoses, pipes, rigid and flexible pipelines, shafts; spatial fixation of some power structures, etc.

M10 mounting screws on the working surface ***Ø50H7*** indicates that during operation it is necessary to eliminate the rotation of the fixed part around the axis. The part has two coaxial holes with diameters ***Ø25H9*** and ***Ø20H9*** , the axis of which is parallel to the axis of the main (***Ø50 H*** *7*) hole, they are located at a distance of ***75mm*** relative to each other and can be intended for fixing in space various nodes of a certain structure relative to each other. The presence of sufficiently strong restrictions on deviations from coaxiality and perpendicularity to the base ***A*** of the holes ***Ø 25H9*** , ***Ø20H9*** and ***Ø 50 H*** *7* , with high requirements for roughness may indicate the use of a clamp in a critical structure of some machine. The holes for the pins in the machine body must be drilled and reamed through the holes in the clamp, which will act as an overhead conductor.

When manufacturing a clamp, special attention must be paid to the processing of two interconnected precision surfaces: the mounting plane ***A*** and the working cylindrical surface with a diameter of ***Ø 50H****7* , the axis of which serves as the base ***B.*** To withstand the size of ***75 ±± 0.1*** mm and the non-parallelism of the axes ***B*** and the common axis of the holes ***Ø 20H9/Ø 25H9*** of no more than ***0.05 mm*** , it is necessary to use boring machines or special devices for machines, if, for example, milling machines are used. In addition, it is necessary to ensure the perpendicularity of the axis ***B*** and the surface ***Ø 20H9*** to the surface ***A*** , i.e. it is advisable to process these surfaces on one machine at one installation. The clamp is made of high-quality ***steel 30L GOST 977-88*** , which has the following chemical composition and mechanical characteristics ***[4].***

Properties of 30L steel:

Heat treatment: Normalization $800 - 900\ ^{o}C$, Tempering $610 - 6\ 30\ ^{o}C$

Material hardness: $HB\ 10^{-1} = 131 - 217\ MPa$

Temperature of critical points: $Ac_{1} = 735, Ac_{3} (Ac_{m}) = 813, Ar_{3} (Arc_{m}) = 796, Ar_{1} = 677$

Weldability of the material: limited weldability . Method of fighting: RDS, ADS under gas protection, ESHS. Heating and subsequent heat treatment is recommended.

Fluke sensitivity: not sensitive.

Tendency to rest fragility: not inclined.

Workability by cutting: in the annealed state at $HB\ 160\ K_{v\ tv.\ spl} = 1.25$ and

$K_{v\,b.st}$=1.0

Temperature of the beginning of solidification , °C: ***1490-1504***

Crack resistance index , K_{so} : ***1.0***

Tendency to the formation of shrinking shells , $K_{u.r.}$: ***1.0***

Fluidity , $K_{zh.t.}$: ***1.0***

Linear shrinkage, % : ***2.2 - 2.3***

Tendency to formation of shrinkage porosity , $K_{u.p.}$: ***1.0***

Mechanical properties in sections up to 100 mm (GOST 977-88)						
Heat treatment modes	**$\sigma_{0.2}$** (MPa)	**σ_{in}** (MPa)	**δ_5** (%)	**ψ** (%)	**KCU** (J/cm^2)	**HRC** ∂ **(HB)**
	no less than					
Normalization 880-900 °C. Tempering 610-630 °C	260	480	17	30	35	(131-217)
Hardening 860-880 °C. Vacation 610-630 °C	300	500	17	30	35	

Table 2.1 Mechanical properties of 30L steel

2.3. Determination of the type and form of production

Type of production is a classification category of production, determined by the breadth of the nomenclature, regularity, stability and volume of production. One of the main quantitative characteristics of the type of production is the coefficient of consolidation of operations ***$K_{ZO.}$*** (***GOST 3.1108-74*** , ***ESTD*** ; ***GOST 14.004-74*** , ***ESTPP***).

The type of production is determined by the coefficient of fixation of operations ***K_{ZO}*** , which is calculated as the ratio of the number of all distinct technological operations that are performed or must be performed by the production unit during the month to the number of workplaces that perform distinct operations.

$$K_{зо} = \frac{\sum_{i=1}^{n} \text{ОП}_i}{\sum_{i=1}^{n} \text{РМ}_i}$$

where $\sum ОП$ is the total number of operations of the technological process;

$\sum PM$ - the total number of workstations where different operations are performed.

The coefficient of consolidation of operations K_{zo} characterizes the number of distinct technological operations performed on average at one workplace of a production unit per month.

Depending on ***the K*** $_{zo,}$ the following types of production are distinguished:

$K_{z.o} = 1$ – mass; $1 \leq To_{z.o.} \leq 10$ – multi-series; $10 \leq To_{z.o.} \leq 20$ – medium-volume; $20 \leq To_{z.o.} \leq 40$ – small series; $K_{z.o.} \geq 40$ – single.

Since we do not have a basic technological process at our disposal, we are unable to determine the type of production using this method .

To determine the type of production in the course project, we will use the analog method (Table 2.2). According to the given annual program of parts production (***2000 pcs.***), as well as as a result of the analysis of the configuration of the part, its mass (***2.75 kg***) and dimensions, it can be stated ***[8]*** that the approximate production for the manufacture of the clamp is ***medium-series*** . For medium-series production, ***a non-flow*** form of production organization is rational. The production section is organized according to the principle of processing structurally similar parts (section of body parts). This section uses universal and specialized equipment, placed in the order of operations. From one workplace to another, parts are transferred in batches using a crane after performing the next operation. The size of the batch of parts ***n*** is determined by the formula:

$$n = (N \cdot t/F) \text{ pcs.} = 2000 \cdot 10/240 = 83 \text{ pcs.}$$

where $N=2000$ - annual program of parts production, pcs.; $t=10$ - number of days for which it is necessary to have a stock of parts (for large parts - ***1, 2, 5*** ; for small parts - ***5, 10, 20***), pcs.; $F=240$ - number of working days in a year (taken equal to ***240…250***), pcs. For simplification, we take a batch ***n = 80 child [3]*** .

Production type	Annual volume of parts production, pcs		
	m ≤ 20 kg	20 ≤ m ≤ 300 kg	m > 300 kg
Single	up to 100	up to 10	from 1 to 5
Small batch	from 100 to 500	from 10 to 200	from 6 to 100

Medium-volume	from 500 to 5000	from 200 to 1000	from 100 to 300
Multi-series	from 5000 to 50000	from 1000 to 5000	from 300 to 1000
Mass	over 50,000	over 5000	over 1000

Table 2.2 Dependence of production type on part mass and series

2.4. Processing of the design of the workpiece and part for manufacturability

The purpose of analyzing the manufacturability of a part is to identify the possibility of reducing the metal content of the product, the complexity of its machining, and the use of high-performance machining methods.

The technological feasibility of a product design (***GOST 14.205-83***) is a set of product design properties that ensure its adaptability to maintaining optimal production costs, maintenance, and repair for existing quality indicators, volume, and conditions of work performed.

Part testing for manufacturability is a part of work to ensure manufacturability, which is aimed at achieving a given level of manufacturability and is performed at all stages of product development.

It is necessary to provide as many surfaces of the part as possible without subsequent machining. The machined surfaces should be simpler, i.e., planes, external and internal cylindrical surfaces, cones, and helical surfaces, because the accuracy and stability of machining are largely determined by the simplicity of the structural forms.

In accordance with ***GOST 14205-83,*** a qualitative and quantitative analysis of manufacturability is planned.

Qualitative analysis of manufacturability

Knowing the type of production, the material of the part and its configuration, you can use the method of casting in sand-clay molds using metal models with machine molding to obtain the workpiece, which provides ***the 9th*** class of casting accuracy in accordance with ***GOST 26645-85*** .

The part has a complex shape and many surfaces that are not machined, that is, these surfaces must be obtained in the workpiece. This shape of the part does not belong to typical representatives of parts obtained by forging or stamping. Obtaining such a shape by any of these methods is either impossible or complicated. It is most expedient to manufacture such a complex workpiece by casting or welding. Since the development of a welded workpiece is a difficult task for course design, we choose a cast workpiece.

The configuration of the casting will be simple enough to ensure easy removal of its model from the mold and, using a rod, obtaining a cast hole for ***Ø50H7*** ; the casting will be formed in two flasks and the casting mold will have a parting line passing through the axes of the circular surfaces ***Ø 70*** and ***Ø 40*** ; the depressions, recesses and ribs (to be processed) have directions perpendicular to the intended plane of the connector; the casting has sufficiently thick walls, which excludes their "non-spill", does not have sharp transitions from thin walls to thick ones; the accuracy class and molding slopes meet the requirements of the standards; the remains of sprues and voids can be combined with the machining allowance (for example, on the ***D surface***); metal waste during machining will be moderate.

In general, the clamp blank is not very technological. When forming in two molds, the surfaces ***A*** and ***K will have an influx along the mold separation line, which somewhat complicates*** their use as a rough base for machining, and forming the blank in one mold is impossible. The clamp is a part of a complex shape with a precise hole perpendicular to the finishing technological and design base ***A.***

Analysis of the manufacturability of the clamp ***[14]*** allows us to draw the following conclusions:

- the shape of the hole of the surface ***Ø70 allows turning the hole Ø50H7*** "through" and milling the surface ***A*** in one operation, obtaining finishing bases for further processing;

- the clamp design ensures free access of cutting and measuring tools to the surfaces being processed;

- the part does not have blind precise holes and does not require trimming of internal or closed ends;

-all machined surfaces and holes are either parallel or placed at right angles to each other;

- the design is characterized by high rigidity and allows for high cutting modes;

- the part has precise surfaces defined by bases ***A*** and ***B*** (the inner surface of the ***Ø50H7 hole*** will be used for basing on base ***B*** (hole axis)) of sufficiently large sizes that can be used as technological bases, using the most common method of basing body blanks - on a plane and two holes on it;

-given the annual production program and configuration, it is impractical to change the material of the part, or to use a welded one instead of a cast workpiece;

- the clamp design provides planes and holes that can be machined with standard tools;

- the maximum dimensions of the part are ***150 mm*** , which makes it possible to use standard metal-cutting machines (including CNC machines), which reduces the cost of production;

- The part has surfaces that are not processed by cutting and to which no strict requirements are imposed (such as the roughness and quality of these surfaces ***h 14*** , ***H14***). The most difficult to process surfaces are: holes ***Ø 50 H 7*** – requires fine reaming, ***Ø25H9*** and

Ø20H9 require fine reaming). Size ***70 H 12*** , groove ***20 H 9*** and Plane ***D*** requires obtaining high-quality roughness and therefore, despite the fact that these surfaces will be machined in one pass, it will be necessary to use small feeds.

In general, there are several comments about the design of the bracket:

- the thickness of the side walls of the ribs (***17mm***) is too high;

- in the hole ***Ø50H7,*** it is also possible to provide a recess in the middle with a width of up to ***30 mm*** and ***Ø52 mm*** , which is obtained using a forming rod (to reduce the complexity of processing and increase the certainty of basing the element located in the hole);

- some difficulties arise when drilling the ***M10-7N hole*** located on the surface of ***G.*** Such its location requires the use of a conductor for drilling. At the same time, the surface of ***G*** is unprocessed, which complicates the basing of the conductor. Also, it is somewhat difficult to process this hole together with the rest of the threaded holes in one operation, although it is not impossible.

- direct measurement of given dimensions given from base ***B*** becomes complicated and requires either a special measuring tool, or the use of auxiliary devices, or the replacement of measuring bases.

To change the design of the clamp in accordance with the above comments, it is necessary to perform calculations and clarify the issue with the designers. Since its specific purpose is unknown, we will leave the design unchanged.

Quantitative analysis of manufacturability

Let us define the quantitative characteristics of manufacturability that characterize the technical characteristics of the design of the part.

The coefficient of manufacturability of the design for the use of material ($\boldsymbol{K}_{VM}$) of the workpiece is determined by the formula:

$$\boldsymbol{K}_{\text{В.М.}} = \frac{\boldsymbol{M}_{\text{Д}}}{\boldsymbol{M}_{\text{З}}}$$

For the manufacturability of the workpiece, it is desirable that the condition ***0.7 be met*** ≤ $\boldsymbol{To}_{VM}$.

where $\boldsymbol{M}_{D}$ is the mass of the finished part, ***kg*** ; $\boldsymbol{M}_{D}$ ***=2.75 kg*** ;

$\boldsymbol{M}_{Z}$ – mass of the workpiece, $\boldsymbol{M}_{Z}$ ***=3.87kg***

Then:

$$\boldsymbol{K}_{\text{В.М.}} = \frac{\mathbf{2.75}}{\mathbf{3.87}} = \mathbf{0.71}$$

According to this indicator, the method of manufacturing the workpiece is technological, but we will check it according to other criteria.

Coefficient of design manufacturability and surface dimensional accuracy $\boldsymbol{K}_{\boldsymbol{TO}}$ determined by the formula:

$$\boldsymbol{K}_{\text{Т.О.}} = \mathbf{1} - \frac{\mathbf{1}}{\boldsymbol{A}_{\text{сер}}} \geq [\boldsymbol{K}_{\text{Т.О.}}] = \mathbf{0.8}$$

where $A_{cp} = \frac{\sum A_i \cdot n_i}{\sum n_i}$ - the average class of product processing accuracy;

n_i – number of dimensions of the corresponding accuracy class;

A – processing accuracy class.

$$\boldsymbol{A}_{\text{сер}} = \frac{\mathbf{7 \cdot 2 + 9 \cdot 3 + 12 \cdot 2 + 14 \cdot 16}}{\mathbf{23}} = \mathbf{12.56}$$

$$\boldsymbol{K}_{\text{Т.О.}} = \mathbf{1} - \frac{\mathbf{1}}{\mathbf{12.56}} = \mathbf{0.92} > [\boldsymbol{K}_{\text{Т.О.}}] = \mathbf{0.8}$$

The coefficient of manufacturability of the structure for surface roughness $\boldsymbol{K}_{\boldsymbol{W}}$ is determined by the formula:

$$\boldsymbol{K}_{\text{Ш}} = \mathbf{1} - \frac{\mathbf{1}}{\text{Б}_{\text{сер}}} \geq [\boldsymbol{K}_{\text{Ш}}] = \mathbf{0.32}$$

where $Б_{cp} = \frac{\sum Б_i \cdot \mathrm{n_i}}{\sum n_i}$ - the average parameter of the product surface roughness; $\boldsymbol{B}$ - the parameter of the surface roughness; n_i - the number of surfaces of the corresponding roughness class.

$$\text{Б}_{\text{сер}} = \frac{\mathbf{0.63 \cdot 3 + 2.5 \cdot 9 + 10 \cdot 11}}{\mathbf{23}} = \mathbf{5.84}$$

$$\boldsymbol{K}_{\text{Ш}} = \mathbf{1} - \frac{\mathbf{1}}{\mathbf{5.84}} = \mathbf{0.828} > [\boldsymbol{K}_{\text{Ш}}] = \mathbf{0.32}$$

So, in total quantitative indicators of manufacturability, it is advisable to consider the part technological.

2.5. Selection of workpiece

According to the requirements of the drawing and as a result of the analysis of the clamp design, we conclude that it is most advisable to use a cast blank. Of all the methods for forming cast blanks in the case under consideration, casting in sand-clay molds with machine molding according to metal models, casting in shell molds, casting according to models that are melted, and casting in metal molds (chisels) can be used. The last three methods allow to ensure a higher quality of castings than casting in sand-clay molds, but they require greater costs for the manufacture of casting equipment and the organization of the foundry section and are more complex. When casting medium-sized blanks from steel into metal molds, the stability of the molds is low and is ***60-100*** castings ***[1]*** .

Considering the dimensions and material of the clamp, low requirements for the quality of castings and the lowest cost of casting in sand-clay molds, the workpiece will be manufactured by casting in sand-clay raw molds from molding mixtures with a humidity of ***3.5*** to ***4.5%*** and a strength of ***60*** to ***120 kPa*** (from ***0.6*** to ***1.2 kgf/cm2***) with a level of compaction to a hardness of not less than ***70*** units (see ***GOST 26645-85***). Machine molding according to metal models. We do not apply heat treatment of the casting. According to ***GOST 26645-85,*** we determine:

- casting dimensional accuracy class – ***9*** ;
- degree of grooving of casting elements – ***4*** ;
- degree of accuracy of casting surfaces – ***13*** ;
- casting mass accuracy class – ***9*** ;
- displacement tolerance due to rod skew – ***1mm*** ;
- casting surface roughness ***Ra 32.0 µm (Rz 120µm)*** ;
- number of allowances for processing the casting – ***6*** .

Thus: casting accuracy ***9-4-13-9 change 1.0 GOST 26645-85*** .

Requirements for steel castings are specified in ***GOST 977-88*** (***steel 30L***), molding slopes are specified in ***GOST 3212-92*** .

For further development of the technological process, the correct choice of the plane of the connector of the casting mold is important. The casting mold should have, if possible, one flat connector and provide a minimum number of rod inserts. Unfortunately, such a plane is not available for the clamp blank. The molds will be separated along the plane of symmetry ***F*** (perpendicular to the base ***A***). The largest dimensions of the blank lie in this plane of separation, which achieves a minimum depth of molding, small differences in the size of the casting due to molding slopes and high quality of the casting; there is an opportunity to abandon the molding slopes, this will almost not complicate the removal of the model.

The casting will be formed in two molds and, therefore, defects are possible on its surfaces, which arise due to the displacement of the molds. Defects can also be caused by the displacement of the rod under the ***Ø50H7 hole*** .

Accuracy class	Nature of production	Number of products per year	Equipment	Production	
				Forms	Stryzhniv
1	From large-scale to mass production	More than 10,000	Metal models and rod boxes, conductors for rod calibration	Machine assembly of rods in conductors	Machine calibration in conductors before assembly
2	From serial to large-scale production	1000…10000	Metal models and rod boxes	Machine	Large ones – machine-made, small ones – manual

Table 2.3 Dependence of the accuracy class of a casting on the nature of production

Note that when molding with the specified plane of the connector of the shape ***F*** , there is no need to provide casting slopes on surfaces ***K*** and ***A*** (base ***A***), but a "defective seam" will be present, therefore they are not recommended for use as installation technological bases in their raw form.

The cast hole ***B*** for ***Ø50H7*** will be formed using a solid cylindrical rod-insert without casting slopes along the length of the hole.

sprues and voids can be combined with the treated surface ***D.***

So, we will manufacture the workpiece by free casting in sand molds and with a production volume of ***2000 pieces*** with a casting weight of no more than ***20 kg,*** we have medium-volume production and ***II*** class of casting accuracy ***[1]*** . Considering that we have medium-volume production, ***it is permissible to obtain holes in the workpiece with a diameter of more 30mm [1]*** . In our case, this will be the diameter of the part ***Ø 50 H 7*** , after calculating the appropriate allowance for its processing.

1.5.1 Development of casting drawings

To develop a casting drawing, it is necessary to determine the maximum dimensional deviations, machining allowances, and other deviations in accordance with ***GOST 26645-85. It is also necessary to assign casting slopes, rounding radii, provide for technological allowances, etc.***

Tolerances of linear and angular dimensions without taking into account displacement and distortion are determined according to ***GOST 26645-85*** .

Unspecified radii of cast fillets are accepted within ***3 - 5 mm*** .

Based on the specified standards and ***GOST 3.1125-88,*** a drawing of the clamp casting was developed, which takes into account casting slopes, transition radii, and machining allowances.

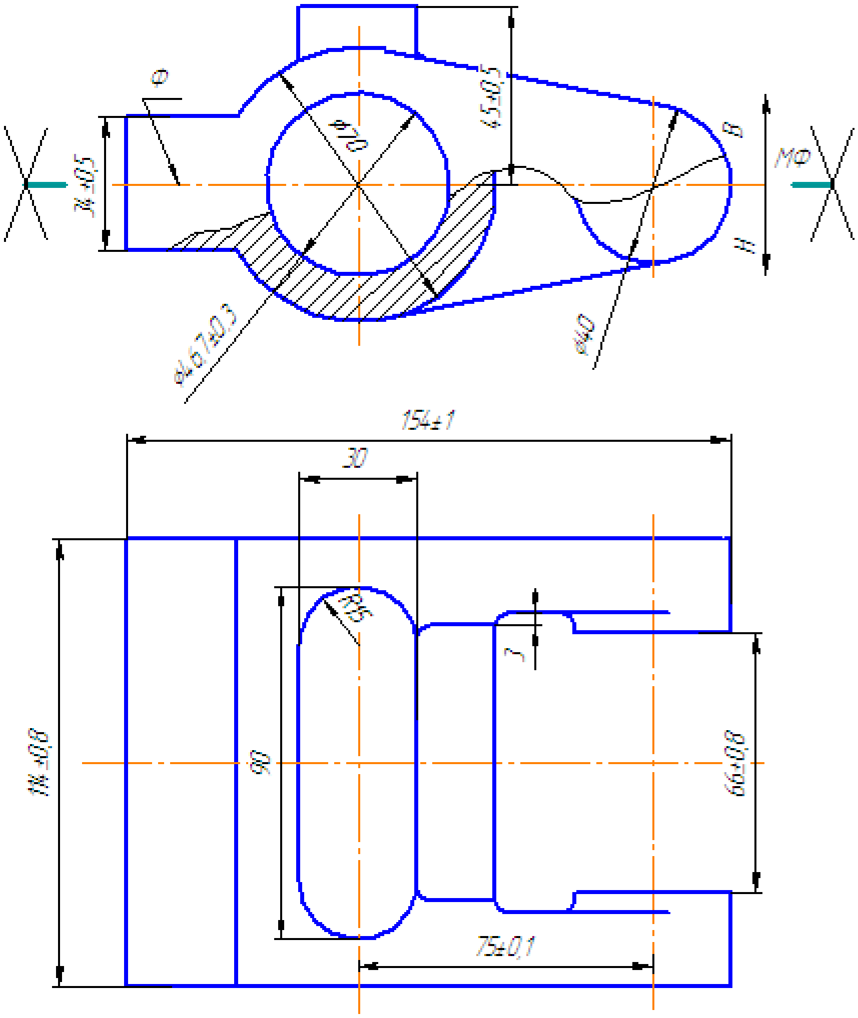


Figure 2.3 Casting drawing

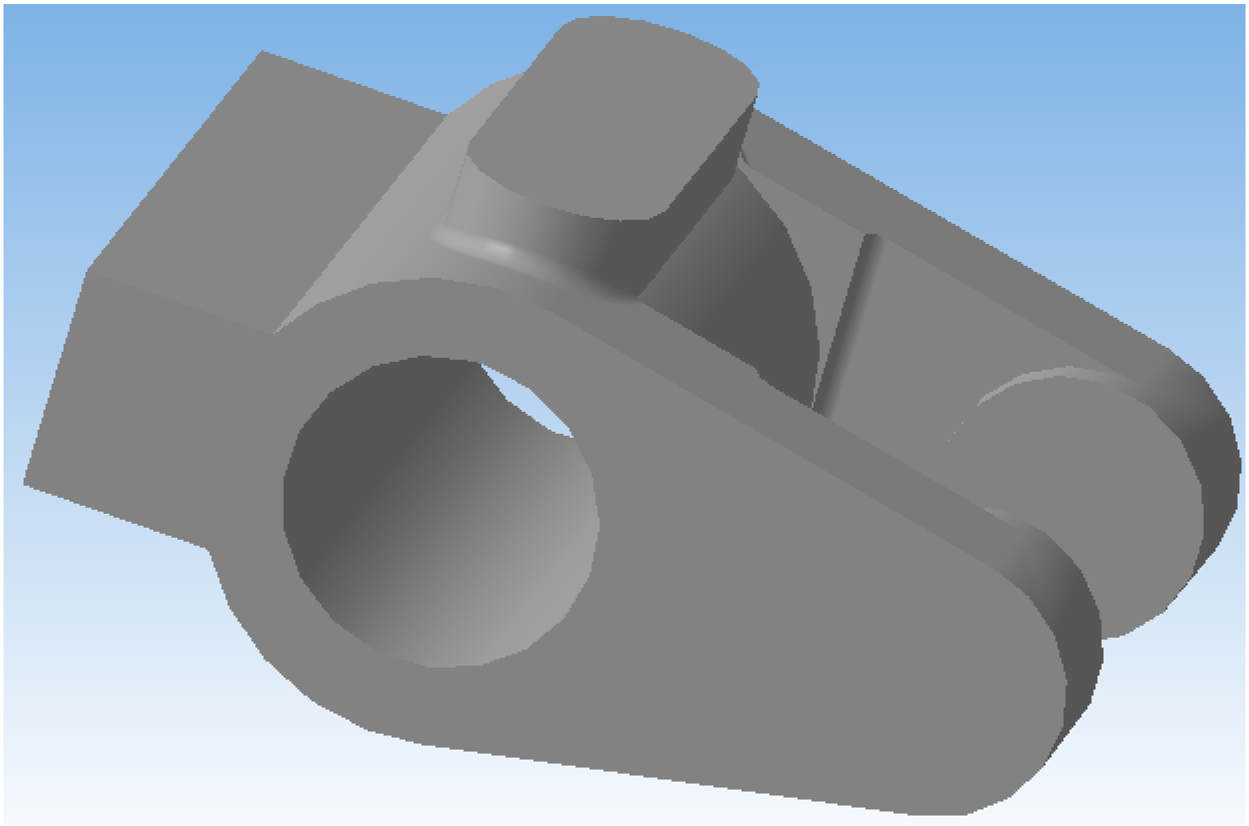


Figure 2.4 3D model of the casting

2.6. Selection of a typical technological process and typical surface treatment schemes

Since the clamp can be classified as a body part, the typical technological process consists of the following stages ***[14]*** :

- processing of a large surface, which will later serve as a finishing installation base;
- drilling and reaming two precise holes on this plane;
- rough and finish machining of large surfaces by milling or broaching;
- rough and finish boring (drilling, countersinking) of the main holes of the body part;
- milling of small secondary planes mainly in one pass;
- drilling, thread cutting, countersinking, reaming shallow holes from different sides of the workpiece;
- finalizing the main precision holes by fine boring, reaming, broaching, grinding (honing), etc.;

- to obtain a given perpendicularity of the ends of the part to the axes of the precise main holes, the final processing of these ends is performed by finishing milling or fine turning (the precise hole serves as the basis).

Based on the requirements specified in the drawing for the quality (accuracy and roughness) of the processed surfaces and the typical technological process, we select typical schemes for their processing ***[8]*** :

The first machining operations should be: machining the plane that is the design base ***A*** ; drilling and reaming two holes on the base plane (***Ø50H7*** and ***Ø20H9***). Further machining:

- processing of other flat surfaces by milling (mostly single-pass);
- milling of the groove ***20N9*** ;
- drilling and reaming of a hole ***Ø25H9*** ;
- drilling, countersinking and threading ***M10-7N*** (5 holes), and drilling two two-stage holes ***Ø12/Ø20*** ;
- processing of size ***70H12*** ;
- cutting a groove (size ***5mm)*** .

Considering the low quality requirements of all flat surfaces (except for the groove), we mill each such surface in one pass (except for surface ***K*** , where two-pass milling is required to obtain the twelfth quality), and surfaces with high roughness requirements are milled with feeds for finishing milling. Based on the recorded previous sequence, we compile a table of surface treatment plans (Table 2.4).

surface	***Surface characteristics***	***Processing plan***
Flat surface (base A)	***Ra2.5, h14***	***Single-pass milling with low feed***
Hole Ø 50H7 (base B)	***Ra0.63, H7***	***Countersinking, precise reaming, fine reaming***
Hole Ø 20H9	***Ra0.63, H9***	***Drilling, reaming is precise***
Flat surface K (size 110 x 12 from base A)	***Ra2.5, h12***	***Rough milling, semi-finishing milling with low feed***
two ledges L and M	***Ra2.5, h14***	***Single-pass milling with low feed***
Size 30 (surfaces F and C)	***Ra10, h14***	***Single milling***
Size 150 (surface E)	***Ra10, h14***	***Single milling***
Flat surface D	***Ra2.5, h14***	***Single-pass milling with low feed***
Groove 20N9	***Ra2.5, H9***	***Rough, semi-finish, finish, fine milling***
Hole Ø 25H9	***Ra0.63, H9***	***Drilling, reaming is precise***
Four vertical holes for M10 thread	***M10-7H***	***drilling***

Horizontal hole for M10 thread (surface B)	M10-7H	drilling
M10 thread (four vertical holes)	M10-7H	Thread cutting with a tap
M10 thread (horizontal hole on surface B)	M10-7H	Thread cutting with a tap
Two holes Ø 12 (surface C)	Ra10, H14	Targeting
Two holes Ø 20 (surface C)	Ra10, H14	Targeting
Surface O (70H12)	Ra2.5, H12	Rough milling, semi-finish milling
5mm slot (surface E)	Ra10, H14	Single milling
Size 20 from A (Surface H)	Ra2.5, h14	Single milling

Table 2.4 Processing plans

2.7. Development of a route technological process

Selection of technological bases and justification of the adopted basing scheme

The quality of manufacturing parts largely depends on the correct choice of technological bases, since the wrong choice distorts the position of the workpiece relative to the tool, leads to an error in the machined surface, creates uneven machining allowances, and can be the cause of defects.

When choosing technological bases, two main principles are followed: unity and constancy of bases. The principle of unity of bases is that a surface (its axis or plane of symmetry) is chosen as the technological base, which is both a design and measuring base. If this is not possible, then the technological base is combined with at least one of them. The principle of unity of bases is used, first of all, to reduce processing errors, as well as to obtain the most rational version of the technological process.

The general algorithm for selecting technological bases involves the selection of general technological bases (***GTB***) at the first stage. In the first operation (if this is not possible - in several operations), it is necessary to obtain a general technological base - a set of workpiece surfaces, which ensures processing in most operations of the technological process with an unchanged workpiece setup. ***GTB*** is found as a result of analyzing the design features of the workpiece. For this, the workpiece surfaces are classified according to their purpose. All surfaces of parts are usually divided into four classes according to their use:

- basic design bases (***OKB***) - used to orient the part during work;

- auxiliary design bases (***DKB***);

- mounting surfaces (***MP***) - used to determine the position of connecting parts and elements;

- free surfaces (***FS***) - all other surfaces of the part.

Based on the clamp drawing and the typical technological process described in subsection ***2.6*** , we will select technological bases and draw up a workpiece processing route and workpiece basing schemes (Fig. 2.5 and 2.6). In this case, it is necessary to try to minimize the number of operations, installations and transitions.

As finishing bases, we will take the plane that is the design base ***A*** , the hole ***Ø 50 H 7*** (design base ***B***), and the hole ***Ø20H9*** . This is a typical choice of finishing bases for body parts. In this way, it will be possible to combine the design bases with the technological ones (Fig. 2.6).

As rough bases, we will take hidden bases ***[9]*** : a plane passing through the points of direct contact of the surface ***Ø70*** with the prism, a plane of separation of the flasks ***F perpendicular to it*** , and a plane of symmetry of the workpiece (Fig. 2.5). We will use a self-clamping, orienting machine tool device designed according to the principle of clamping in prisms.

As is known ***[9]*** , the total number of bonds imposed on the workpiece by a directed clamp is equal to

$$n = m - k ,$$

where n – the number of links, m – the number of support points of the clamp and k – the number of degrees of freedom of the working surface of the clamp. The first prism, which provides two support points for the diameter ***Ø70*** and serves as a fixed support. The other prism will "support" the surfaces ***B*** and ***D*** , and according to the above formula will leave the workpiece with three degrees of freedom. Both together impose five constraints, leaving the workpiece with one degree of freedom and basing the workpiece on the plane ***F*** and the plane of the contact points ***of Ø70*** with the prism ***[9]*** . The wedge-plunger mechanism will base the workpiece on the axis of symmetry.

As already noted in section ***2.5*** - on surfaces ***A*** and ***K*** , as well as on the internal surfaces of the workpiece relative to them There may be a "seam" from casting along the joint of the molds, which complicates basing along the axis of symmetry. Therefore, when designing a machine tool, care must be taken to ensure that the wedge-plunger mechanism, when basing the workpiece in the device, contacts the internal surfaces below or above the line of separation of the molds. In this case, in order to simplify the fastening of the workpiece in the device and its removal from the device after processing, it is desirable to place the plunger mechanism as low as possible.

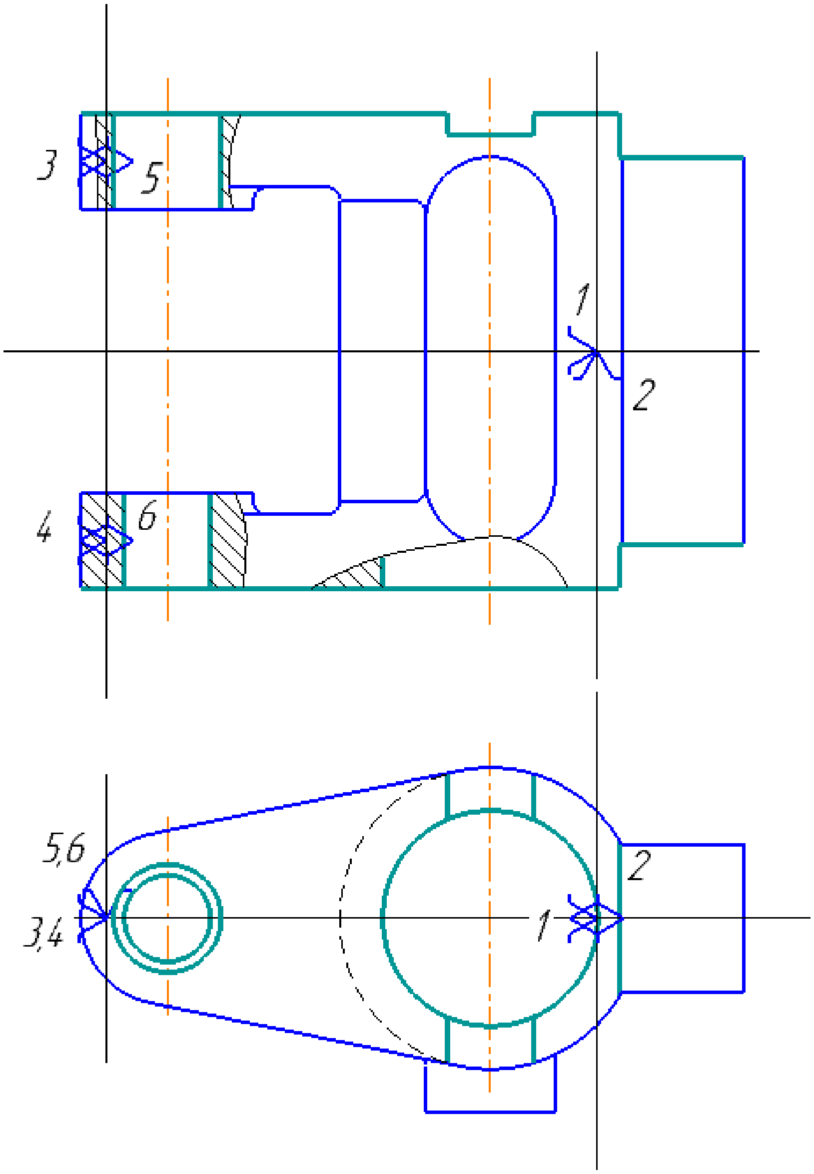


Figure 2.5 Basing schemes and processing plans (005)

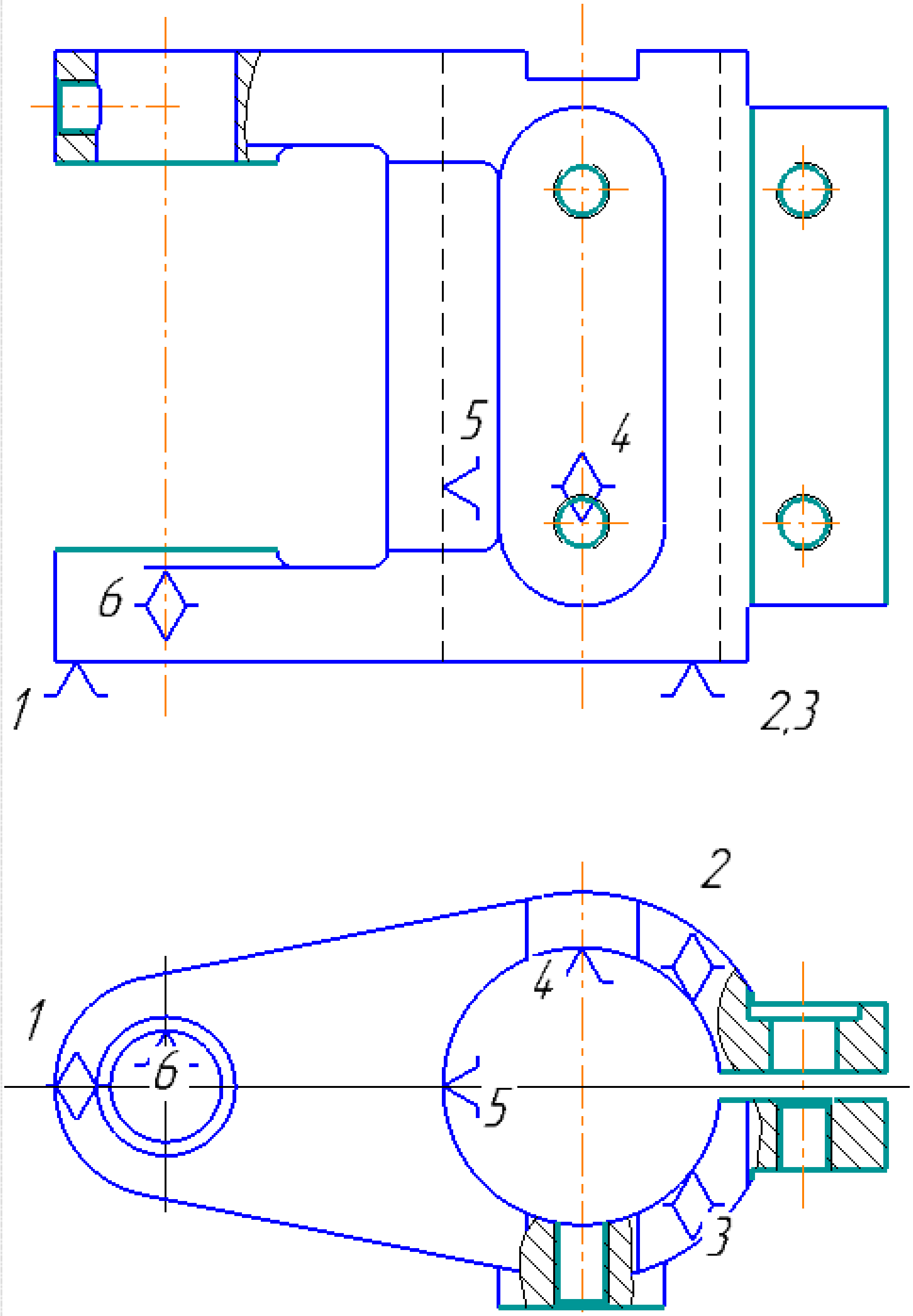


Figure 2.6 Basing schemes and processing plans (010)

Compilation of route technological process

Operation 005. Horizontal milling with CNC

Milling of plane ***A.*** Rough and semi-finish milling of size ***110 h 12*** (surface ***K***), ledges ***L*** and ***M.*** Milling of groove ***20H9*** . Countersinking, precise reaming and fine reaming ***Ø50H7*** ; drilling and precise reaming of holes ***Ø20H9*** and ***Ø25H9*** .

As bases, as already noted above, we take the plane ***H*** passing through the points of direct contact of the surface ***Ø 70*** with the prism (Fig. 2.5), the plane of separation of the flasks ***F perpendicular to it*** , and the plane of symmetry of the workpiece.

Operation 010. Horizontal milling with CNC

Single-pass milling of surfaces ***E*** , ***D*** , ***G*** and ***C.*** Single-pass milling of surface ***H*** , rough and semi-finish milling of surface ***O*** (size ***70H12***). Milling a ***5mm slot*** on surface ***E.*** Centering and drilling five holes ***Ø8.5 for M10-7H*** thread (two holes on surface ***G*** will harden through, for subsequent tapping). Tapping two holes on surface C ***with*** a two-stage tapping tool ***Ø12/Ø20*** . Countersinking chamfers ***1x45 °. Tapping with M10-7H*** tap .

As bases we choose: installation base – surface ***A*** (three reference points), guiding base – axis ***B*** (inner surface of hole ***Ø50H7***) and it gives 2 reference points. Reference base – hole ***Ø20H9*** (one reference point). We fix the workpiece horizontally (the highest surface – ***K***) by placing axis ***B*** vertically (Fig. 2.6). This will make it possible to process all the specified surfaces without changing the installation to ensure access to the tool.

The decisions made largely coincide with the recommendations given in ***[14]*** for the manufacture of body parts, which allows us to count on obtaining high-quality parts.

When developing and justifying the adopted technological process, we limited ourselves to logical considerations based on well-known recommendations ***[1, 3, 8]*** and experimental and statistical data, which is acceptable for medium-scale production. For multi-series, especially for mass production, the correctness of the decisions made must be proven using specific economic calculations and accuracy calculations.

Selection of equipment, machine tools, cutting and measuring tools

For medium-scale production, highly productive universal and specialized equipment is selected, focusing on the correspondence of the main dimensions of the working bodies of the machine to the overall dimensions of the workpiece being processed and achieving the required accuracy, as well as on the use of a minimum number of different machine models.

To achieve high quality and productivity in the manufacture of the clamp, in all operations, according to the recommendations given in ***[3; 8]*** , special devices with high-speed clamping of workpieces are used for serial production.

The processing is performed with a standard tool. The material of the cutting part of the end mill is hard alloy ***T15K6*** . Let us take into account that to achieve maximum productivity in end milling, it is recommended to use small-diameter cutters, the size of which is ***10-20%*** larger than the width of the machined surface, with a large number of teeth. For drilling, reaming holes and threading, we will use tools made of high-speed steel ***P6M5*** and others ***[1, 15]*** .

Operation 005.

a Haas EC ***-400*** CNC horizontal milling machine with an additional fourth axis with the following characteristics: pallet size ***400x400mm*** ; spindle bore – ***ST 40 cone*** (***ISO 40***); spindle speed – ***8000 rpm*** ; maximum feed rate during cutting ***12.7m/min*** ; rapid movements – ***25.4m/min*** ; spindle drive motor power ***N = 14.9 kW*** .

In general, according to the method given in ***[3]*** , the denominators of the geometric progression of the series of speed boxes and feed boxes of the machine for optimizing cutting modes (selection of parameters as close as possible to the calculated ones) are determined.

However, modern CNC machines are equipped with stepless systems for regulating the spindle speed and the feed rate of the machine's working elements (table, spindle, etc.), so when determining cutting modes, their calculated values can be assigned.

For milling surface ***A*** , roughing and semi-finishing milling of size ***110 h 12*** (surface ***K)*** ***a Ø100*** end mill is used , ***z= 10*** (***GOST 9473-80) with insert knives equipped with T15K6*** carbide inserts . The absence of smaller diameter cutters in the standard does not allow the tool to be used with maximum efficiency. The cutter is mounted on a mandrel (***GOST 26541-85***). The processing should be carried out with a feed for finishing milling, to achieve high-quality roughness in one pass.

Milling of ***the 20N9 groove*** should be performed with an end mill made of high-speed steel ***P6M5*** , with a cylindrical shank, ***Ø16.0*** , ***z =6*** (***GOST 17025-71***).

Milling of ***L*** and ***M ledges*** – end mill with cylindrical shank equipped with helical carbide (***T15K6***) inserts. Mill diameter ***Ø32*** , number of teeth ***Z = 4*** (***GOST 20537-75***).

To process hole ***B*** (***Ø50H7***), we use a countersink with carbide plates (***T15K6***) with a conical shank according to ***GOST 3231-71*** . Machine reamers, with insert knives made of high-speed steel ***P6M5*** with a conical shank according to ***GOST 883-80 [1, vol. 2]*** . The countersink and reamers are mounted in a milling mandrel with a Morse taper 4. Measuring tool: ***ШЦ-II-250-0.05*** , ***Caliper plug Ø50H7*** .

Processing of the hole ***Ø20N9*** : twist drill ***2300-5756*** , made of high-speed steel ***P6M5*** with a cylindrical shank, short series according to ***GOST 4010-77 [1, vol. 2]*** ; solid reamer, with a conical shank according to ***GOST 1672-80*** (alloy ***P6M5***).

Drilling and precise reaming of a hole ***Ø25H9*** – twist drill, made of high-speed steel ***R6M5*** with a conical shank according to ***GOST 10903-77*** ; one-piece reamer, with a conical shank according to ***GOST 1672-80*** (alloy ***R6M5***). To fix the tool, use milling arbors with quick-change collets and adapter arbors with a Morse taper. Measuring tool: ***ShTs-II-250-0.05*** .

Since the main processing time will be quite long compared to the auxiliary one, the processing is carried out in a single-seat device.

Operation 010.

Milling a ***5mm slot*** on the ***E surface*** – a slotted disk cutter made of high-speed steel ***R6M5*** , diameter ***Ø160*** , width ***B = 5*** , ***z =100*** (***GOST 2679-93***).

single-pass milling of planes ***D*** and ***E with a Ø100*** end mill , ***z= 10*** (***GOST 9473-80) with insert knives equipped with T15K6*** carbide inserts . Machining of the ***Z*** and ***Z planes*** should be performed with an end mill made of high-speed steel ***P6M5*** , with a cylindrical shank, ***Ø25.0*** , ***z =6*** (end mill ***2220-0218 GOST 17025-71***).

To attach the cutters, use milling arbors for end mills.

Single-pass milling of surface ***H*** , rough and semi-finish milling of surface ***O*** (size ***70H12***) is performed with an end mill made of high-speed steel ***P6M5*** , with a cylindrical shank, ***Ø25.0*** , ***z =6*** (End mill ***2220-0218 GOST 17025-71***).

Centering and drilling five holes ***Ø8.5*** for ***M10-7N thread*** - twist drill, made of high-speed steel ***R6M5*** with a cylindrical shank, medium series according to ***GOST 10902-77*** (drill ***2300-0200***), Centering drill ***2317-0004*** according to ***GOST 14952-75, R6M5*** .

Countersinking chamfers ***1x45*** ° . For chamfering, a conical countersink made of high-speed steel ***R6M5*** (***GOST 14953-69***) is used. Countersinking two holes on the surface ***With*** a two-stage countersink ***Ø12/Ø20 2350-0702 GOST 26258-87*** . Thread cutting with a tap ***M10-7N*** . For thread cutting, machine taps made of high-speed steel ***R6M5 ,*** size ***M10-7N*** with a working part length ***of 24 mm*** according to ***GOST 3266-81 , are used*** .

The tool is mounted in collet chucks.

Measuring instrument: ***ShTs-II-250-0.05*** .

Due to the long processing time of the workpiece, the device is used as a single-person unit for this operation.

Finalization of the processing route

A 005 Horizontal milling machine with CNC

Used HAAS EC-400

AT

1. Install and secure the workpiece
2. Mill the plane once, maintaining size 1
3. Mill the plane beforehand, maintaining size 12 (110.6)

4. Mill the plane completely, maintaining size 12
5. Mill two ledges sequentially, maintaining dimensions 4, 5 and 6
6. Mill the groove maintaining dimensions 3 and 10
7. Mill the groove, maintaining dimensions 3 and 7 (19)
8. Mill the groove completely, maintaining dimensions 3 and 7.
9. Drill a hole through, maintaining size 11 (Ø 19.75)
10. Ream the hole, maintaining size 11
11. Drill a hole through, maintaining size 2 (Ø 24.75)
12. Ream the hole while maintaining size 2
13. Countersink the hole through, maintaining size 8 (Ø 49.6)
14. Pre-drill the hole, maintaining size 8 (Ø 49.95)
15. Ream the hole completely, maintaining size 8.
16. Remove the workpiece

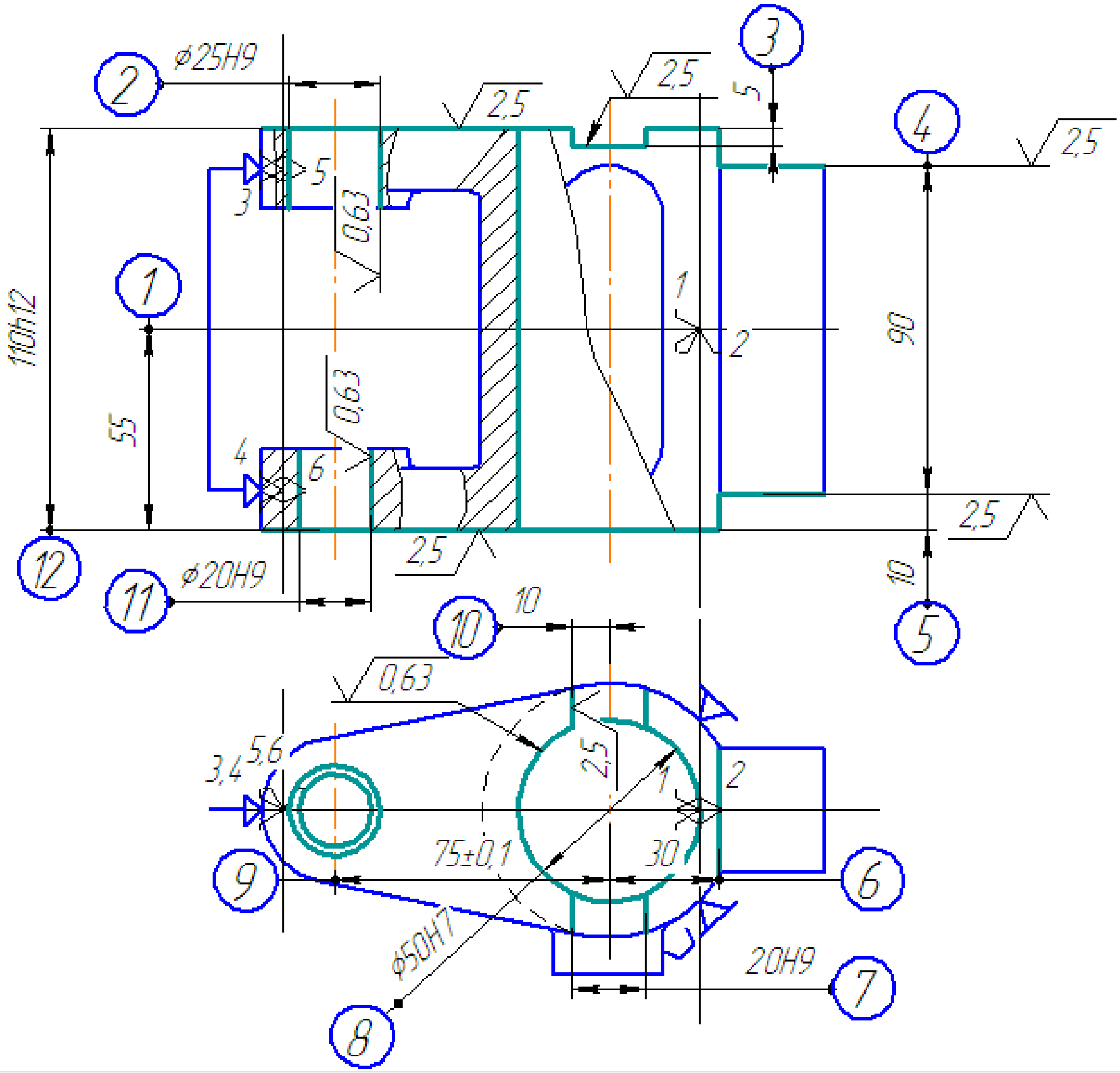


Figure 2.7 Sketch for operation 005

A 010 Horizontal milling machine with CNC

Used HAAS EC-400

AT

1. Install and secure the workpiece
2. Mill the plane once, maintaining size 13
3. Mill the plane once, maintaining size 12
4. Mill two surfaces sequentially, maintaining size 9
5. Mill the surface once, holding the size 14
6. Mill the surface beforehand, maintaining size 15 (70.5)
7. Mill the surface completely, maintaining size 15

8. Mill the slot, maintaining size 11
9. Center 5 holes, maintaining dimensions 1, 2, 4 and 5
10. Drill 5 holes, maintaining size 3 (Ø 8.5)
11. Drill two holes, measuring 6, 7, 8.
12. Countersink five holes, maintaining size 10
13. Cut a thread in five holes, maintaining size 3
14. Remove the workpiece

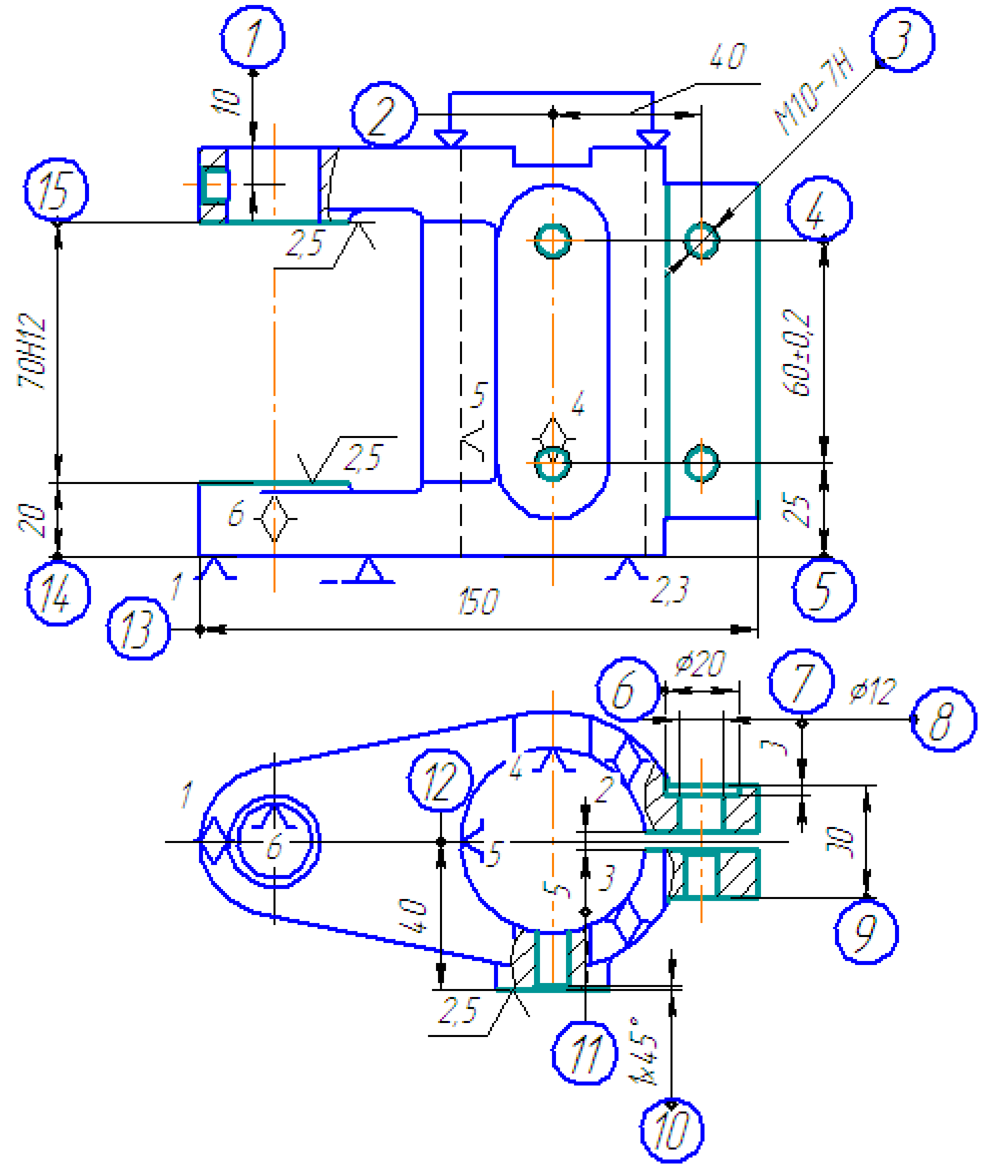


Figure 2.8 Sketch for operation 010

2.8. Development of an operational technological process

Determination of machining allowances

Determination of allowances by calculation and analytical method

The workpiece has a hole obtained by casting for further machining to the size ***Ø50 H 7.*** We will calculate the allowance for machining this hole using the computational-analytical method of determining allowances.

The minimum machining allowance is calculated using the formulas:

$$\textit{with parallel processing: } 2Z_{i\,min} = 2[(Rz+h)_{i-1} + \Delta_{\Sigma_{i-1}} + \varepsilon_i]$$

$$\textit{with sequential (one-sided) processing:} Z_{i\,min} = (Rz+h)_{i-1} + \Delta_{\Sigma_{i-1}} + \varepsilon_i$$

$$\underline{\textit{for holes }}\textit{: } 2Z_{i\,min} = 2[(Rz+h)_{i-1} + \sqrt{\Delta_{\Sigma_{i-1}}{}^2 + \varepsilon_i{}^2}]$$

Maximum allowance for surface treatment: external

$$Z_{i\,max} = Z_{i\,min} + TD_{i-1} - TD_i$$

$$2Z_{i\,max} = 2Z_{i\,min} + TD_{i-1} - TD_i$$

Internal

$$Z_{i\,max} = Z_{i\,min} + Td_{i-1} - Td_i$$

$$2Z_{i\,max} = 2Z_{i\,min} + Td_{i-1} - Td_i$$

WhereTD_{i-1} andTd_{i-1} – dimensional tolerances on the previous pass; TD_iandTd_i – tolerances on the transition being performed.

Also hereRz_{i-1} – height of profile irregularities on the previous transition, h_{i-1}– depth of the defective surface layer on the previous transition, $\Delta_{\Sigma_{i-1}}$– total deviation of the location of the surfaces, ε_i– error in securing the workpiece at this transition ***[1, 3]*** .

The technological route for processing a ***Ø50H7 hole*** consists of three transitions: countersinking, precision turning, and fine turning, performed at one installation (in roughing bases). We draw up a map for calculating allowances.

We enter the specified parameters and all tabular data (regarding ***h*** , ***ε*** , ***Δ***).

Total value of ***Rz*** and ***h*** , which characterizes the surface quality after casting, is equal to ***600 µm*** . We enter the specified parameters and all tabular data (***h*** , ***Rz*** , ***T***). Spatial deviations when using diameter ***Ø70*** as a base:

$$\Delta_\Sigma = \sqrt{\Delta_{зм}{}^2 + \Delta_ц{}^2},$$

where $\varDelta_ц$ – displacement during centering in the prism, $\Delta_ц = \sqrt{T^2/2 + 0.25^2} = \sqrt{0.74^2/2 + 0.25^2} = 578$мкм, ***[3, p. 69]*** (***T=740μm*** – casting tolerance); rod displacement – $\Delta_{зм} = {}^{S}/_{\cos\beta} = {}^{0/15}/_{\cos 15°} = 155$мкм, ***S = 0. 1 5mm*** – gap between the mold and the rod, ***β=15° [1, vol. 1, p. 184]*** .

Then:

$$\varDelta_\Sigma = \sqrt{578^2 + 155^2} = 598\text{мкм}.$$

Final spatial deviation after countersinking:

$$\Delta_{\Sigma 1} = k = 0.005\ \Delta_\Sigma \cdot 598 = 3\mu m\ ,$$

Further, spatial deviations will be too small and are not taken into account.

The installation error ε_{in} the transition that is performed is characterized by the displacement of the machined surface in one direction or another when basing and fixing the part in the device. It is determined by the formula ***[1, 3]*** :

$$\varepsilon_у = \sqrt{\varepsilon_б^2 + \varepsilon_з^2},$$

where ε_b , ε_c - the basing and anchoring errors, respectively.

The basing error occurs when the technological and installation bases do not coincide, in our case it is equal to ***[1]*** :

$$\varepsilon_б = \frac{T}{2} \cdot \frac{1}{\sin\alpha} = \frac{740}{2} \cdot \frac{1}{\sin 45°} = 523.26\text{мкм} \approx 524\text{мкм}$$

where ***T =740μm*** – tolerance for casting of size ***Ø70*** according to the fourteenth quality, ***α =90*** ° – prism angle. Fixing error ***[3, p. 82]*** when installed on support plates $\varepsilon_C = 60\mu m$.

So

$$\varepsilon_у = \sqrt{524^2 + 60^2} = 527\text{мкм}.$$

After countersinking: $\varepsilon_у{}' = 0.005 \cdot 527 \approx 3$мкм, and after precise turning, the fixing error is not taken into account.

Minimum allowance for pre-countersinking: 2 Z $_{min}$ $= 2\left(600 + \sqrt{598^2 + 527^2}\right) =$

$= 2794$мкм, ***2 Z $_{max}$ = 2794 +620-160 = 3254μm;***

For accurate unfolding: 2 Z $_{min}$ $= 2 \cdot \left(50 + 50 + \sqrt{3^2 + 3^2}\right) = 208$мкм, ***2 Z $_{max}$ = 208+160-39 = 329μm;***

For fine turning: $2Z_{min} = 2(5+10) = 30\mu m$, $2Z_{max} = 30+39-25 = 44\mu m$.

Limit dimensions according to formulas: for external

$$a_{min\,i-1} = a_{min\,i} + Z_{min\,i}$$

$$a_{max\,i-1} = a_{min\,i-1} + T_{i-1}$$

<u>for holes</u>

$$D_{min\,i-1} = D_{max\,i-1} - T_{D\,i-1}$$

$$D_{max\,i-1} = D_{max\,i} - 2Z_{min\,i}$$

Exact unfolding: D_{max}= 50.025-0.03 = 49.995mm, $D_{min\,i}$= 49.995 – 0.039 =49.956mm.

Countersinking: D_{max}= 49.995 – 0.208 = 49.787mm, $D_{min\,i}$= 49.787 – 0.16 = 49.627mm

Workpiece: : D_{max}= 49.787 – 2.794 = 46.993mm, $D_{min\,i}$= 46.993 – 0.62 = 46.373mm

Finally, we determine the size of the hole in the casting: ***(46.373+46.993)/2= <u>46.683</u>*** .

We accept:

46.7 ±0. 3

Audit:

$$T_{\text{заг}} - T_{\text{дет}} = 620 - 25 = 595$$

$$\sum 2Z_{max} - \sum 2Z_{min} = 3254 + 329 + 44 - 2794 - 208 - 30 = 595\text{мкм}$$

Surface treatment process route	***Allowance elements, microns***	***Manufacturing tolerance T ,***	***Accepted (rounded) values of dimensions for transitions, mm***	***Limit allowances, microns***

	Rz	***h***	***Δ***	***ε***		***min***	***max***	***min***	***max***
Size Ø 50H7									
Sand casting17	***600***		***598***	***-***	***620***	***46.373***	***46,993***	***-***	***-***
Countersinking 10-11	***50***	***50***	***3***	***527***	***160***	***49.627***	***49.787***	***2794***	***3254***
Precise deployment 8	***5***	***10***	***-***	***3***	***39***	***49.956***	***49.995***	***208***	***329***
Thin deployment7	***3.2***	***5***	***-***	***-***	***25***	***⌀ 50 H7***		***30***	***44***

Table 2.5 Allowance calculation chart

Determination of allowances by tabular method

By ***[2]*** and ***GOST 2009-55*** we accept the following tabular values of allowances for the following casting surfaces:

Size ***110 h 12 (planes A/K) – 4 ± 0.8mm*** , size ***30 (planes G and Z) – 4 ± 0.5mm*** , size ***150 (plane E) – 4 ± 1.0mm , plane D – 5 ± 0.5mm*** , size ***70 h 12 – 4 ± 0.8mm*** .

We summarize the finally obtained allowances in Table 2.6:

Surface	***Size***	***Allowance***	***Admission***
A/C	***110***	***4***	***± 0.8***
THERE ARE	***150***	***4***	***±1.0***
F/W	***30***	***4***	***±0.5***
D	***40***	***5***	***±0.5***
B	***⌀ 50***	***3.3***	***±0.3***
70 h12	***70 h12***	***4***	***± 0.8***

Table 2.6 Machining allowances

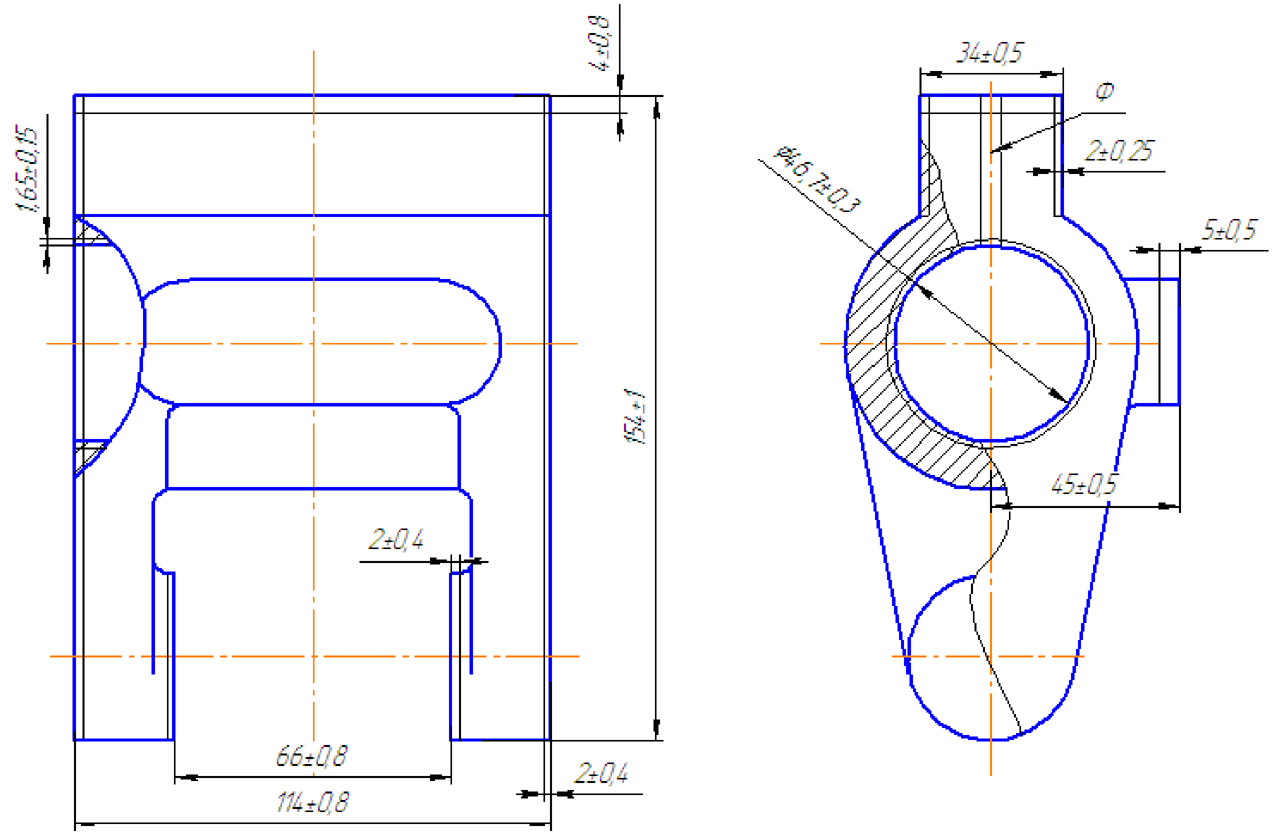


Figure 2.9 Machining allowances

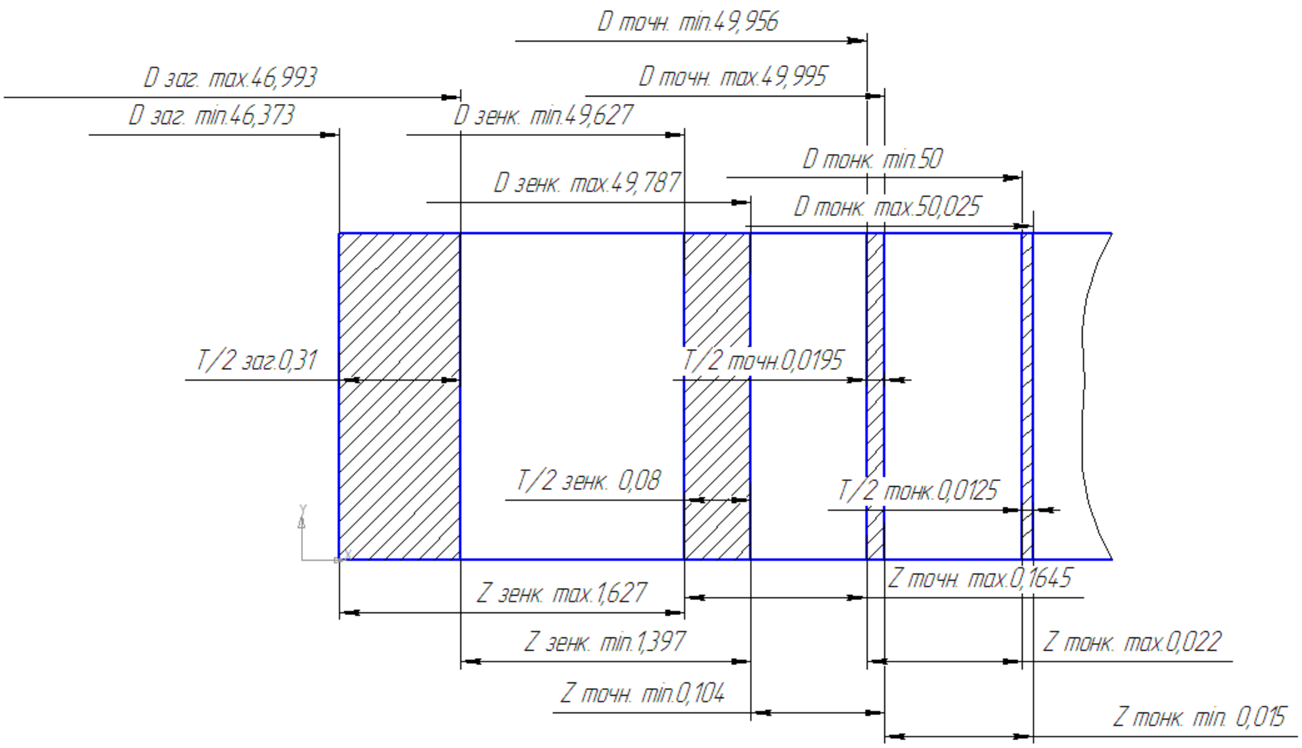


Figure 2.10 Layout of allowances and tolerances for machining a Ø50H7 hole

Definition of cutting modes

Determination of cutting modes by the computational-analytical method

Calculation of cutting mode for milling surface A

It is necessary to calculate the cutting mode for single-pass milling of plane ***A.***

Initial data: the material being processed is ***30L steel ; equipment is a Haas*** EC ***- 400*** CNC horizontal milling machine ; tool is a ***Ø100 face milling cutter*** , ***Z = 10*** (***GOST 9473-80) with insert knives with T15K6*** carbide inserts . In order to avoid “undermining” the workpiece with the clamp, we choose a right-hand cutter; geometric parameters of the cutting part of the cutter ***[1, 16]*** ; $\gamma = 5°$, $\alpha = 7°$, $\varphi = 45°$, $\varphi_1 = 5°$; $\lambda = 13°$length of the machined surface ***is 150mm*** , width (maximum) is ***70mm*** .

We choose the feed rate $S_{rev} = 0.4$ ***mm/rev*** , feed per tooth – $S = S_{rev} / Z = 0.4 / 10 = 0.04$ ***mm/tooth*** .

The stability period of the cutter ***T =is 180 min*** .

Cutting speed allowed by tool stability:

$$V_i = 1.1 \frac{C_V D^{q_v}}{T^m h^{x_v} S^{y_v} B^{u_v} Z^{p_v}} K_V \text{ м/хв}$$

For the given conditions: $K_V = K_{\text{м}v} K_{\text{п}v} K_{иv} = 1.0\left(750/490\right)^{1.0} \cdot 0.8 \cdot 1.15 = 1.4$, the coefficient ***1.1*** in the formula for cutting speed takes into account the influence of the main angle in the plan ***ϕ =45*** ° .

Then

$$V_i = 1.1 \frac{332 \cdot 100^{0.2}}{180^{0.2} 2^{0.1} 0.04^{0.4} 70^{0.2} 10^{0}} 1.4 = 656.9 \text{ м/хв}$$

The calculated spindle speed that the stability of the milling cutter allows:

$$n_i = \frac{1000 V_i}{\pi D} = \frac{1000 \cdot 657}{\pi \cdot 100} = 2091 \text{ об/хв}$$

Circumferential cutting force during milling:

$$P_Z = 10 \frac{C_p h^{X_p} S^{Y_p} B^{U_p} z}{D^{Q_p} n^{\omega_p}} K_p \text{ Н}$$

For these conditions:

$$P_Z = 10 \frac{825 \cdot 2^{1.0} \cdot 0.04^{0.75} \cdot 70^{1.1} \cdot 10}{100^{1.3} \cdot 2091^{0.2}} \left(490/750\right)^{0.3} = 757 \text{ Н}$$

Torque on the machine spindle:

$$M_{\text{кр}} = \frac{P_z D}{2 \cdot 100} = M_{\text{кр}} = \frac{757 \cdot 100}{2 \cdot 100} = 378.5 \text{ Н} \cdot \text{м}$$

Cutting power on the machine spindle:

$$N = \frac{P_z v}{1000 \cdot 60} = \frac{757 \cdot 656.9}{1000 \cdot 60} = 8.3 \text{ кВт}$$

Since the calculated power is less than the effective power of the machine (***N = 8.3kW <Ne –14.9kW***), the milling speed will be limited only by the stability of the tool.

Estimated value of the minute feed of the table with the workpiece

$$S_{\text{хв}} = S_{\text{об}} \cdot n = 0.4 \cdot 2091 = 836.4 \text{ мм/хв}$$

The selected machine allows for stepless adjustment of spindle speed and feed rates. In addition, the obtained values of spindle speed and feed rate belong to the operating range of the machine, so we finally accept the calculated speed values.

Finally, the milling mode of surface ***A*** is as follows: ***h=2mm*** ; ***S=0.04mm/tooth*** ; ***S*** $_{rev}$ ***=0.4mm/rev*** ; ***S*** $_{min}$ ***=836.4mm/min*** ; ***n=2091rev/min*** ; ***V=656.9m/min*** ; ***P*** $_{Z}$ ***= 757H*** .

Calculation of cutting modes for countersinking a hole Ø50H7

Initial data: the processed material is ***30L steel ; equipment is a Haas*** EC ***- 400*** CNC horizontal milling machine ; tool is a ***Ø49.6 countersink with T15K6*** carbide inserts (***countersink 2320-5765 T15K6 GOST 3231-71***); number of teeth ***Z = 3.*** Inserts ***25230 GOST 25424-82*** .

The countersinking mode is calculated according to the method given in ***[1]*** . Depth of cut when countersinking $h = {}^{(D_{\text{зенк}} - D_{\text{отв}})}/_{2} = {}^{(49.6 - 46.7)}/_{2} = 1.45$ мм. The feed is taken based on recommendations ***1, vol. 2, p. 277]*** $S = (K_{OS} = 0.7) \cdot (S_{\text{рек}} = 1.0) = 0.7$ мм/об. According to ***[1],*** we assume the countersink stability period ***T =60 min*** . The cutting speed allowed by the tool stability is determined by the formula:

$$V = \frac{C_v \cdot D^q \cdot K_v}{T^m \cdot S^Y \cdot h^x} \text{ м/хв}$$

where C_v***=18.0*** , ***q =0.6*** , ***y =0.3*** , ***m =0.2 5*** , ***x = 0.2 [1, vol.2, p. 279]*** .

Total correction factor

$$K_v = K_{\text{м}v} K_{\text{п}v} K_{\text{и}v}$$

For the given conditions: $K_V = K_{\text{м}v} K_{\text{и}v} K_{iv} = 1.0\left({}^{750}/_{490}\right)^{1.0} \cdot 0.8 \cdot 1.15 = 1.4$, ***[1, vol. 2, p. 277]*** .

Therefore:

$$V = \frac{18.0 \cdot 49.6^{0.6} \cdot 1.4}{60^{0.25} \cdot 0.7^{0.3} \cdot 1.45^{0.2}} = 97.35 \text{ м/хв}$$

The calculated spindle speed allowed by the stability of the countersink:

$$n_i = \frac{1000 V_i}{\pi D} = \frac{1000 \cdot 97.35}{\pi \cdot 49.6} = 624.7 \text{ об/хв}$$

We assume ***n =625 rpm*** and ***v =97.4 m/min*** .

Torque according to the formula:

$$\boldsymbol{M}_{\text{кр}} = \mathbf{10} \cdot \boldsymbol{C_M} \cdot \boldsymbol{D^q} \cdot \boldsymbol{h^x} \cdot \boldsymbol{s^y} \cdot \left(\boldsymbol{K_p} = \left(\frac{\boldsymbol{\sigma}_{\text{в}}}{\mathbf{750}}\right)^{\boldsymbol{n}} = \left(\frac{\mathbf{490}}{\mathbf{750}}\right)^{\mathbf{0.75}}\right) =$$
$$= \mathbf{10 \cdot 0.09 \cdot 49.6^{1.0} \cdot 1.45^{0.9} \cdot 0.7^{0.8} \cdot 0.726 = 34}\ \text{Н} \cdot \text{м}$$

Axial force:

$$\boldsymbol{P}_{\text{о}} = \mathbf{10} \cdot \boldsymbol{C_p} \cdot \boldsymbol{h^x} \cdot \boldsymbol{s^y} \cdot \left(\boldsymbol{K_p} = \left(\frac{\boldsymbol{\sigma}_{\text{в}}}{\mathbf{750}}\right)^{\boldsymbol{n}} = \left(\frac{\mathbf{490}}{\mathbf{750}}\right)^{\mathbf{0.75}}\right) = \mathbf{10 \cdot 67 \cdot 1.45^{1.2} \cdot 0.7^{0.65} \cdot 0.726}$$
$$= \mathbf{602.5}\ \text{Н}$$

Cutting power:

$$\boldsymbol{N} = \frac{\boldsymbol{M}_{\text{кр}} \cdot \boldsymbol{n}}{\mathbf{9750}} = \frac{\mathbf{34 \cdot 625}}{\mathbf{9750}} = \mathbf{2.18}\ \text{кВт}$$

the less power on the machine spindle.

, for countersinking a hole ***Ø50H7,*** we take: ***h=1.45mm*** ; ***S_{rev}=0.7mm/rev*** ; ***S_{min} =437.5mm/min*** ; ***n=625rev/min*** ; ***V=97. 4 m/min*** ; ***P_o = 602.5H*** ; ***N = 2. 18kW; M_{KR} = 34N m*** .

Calculation of cutting modes for precise reaming of a Ø50H7 hole

Initial data: material to be machined – ***30L steel ; equipment – Haas*** EC ***- 400*** CNC horizontal milling machine ; tool – ***Ø50 reamer*** with finishing allowance with insert knives made of high-speed steel ***P6M5*** , ***z =6*** , main angle in plan ***ϕ =45*** ° (***scan 2364-0349 2 GOST 883-80***).

Depth of cut when turning $\boldsymbol{h} = {}^{(\boldsymbol{D}_{\text{разв}} - \boldsymbol{D}_{\text{зенк}})}\!/_{\mathbf{2}} = {}^{(\mathbf{49.95 - 49.6})}\!/_{\mathbf{2}} = \mathbf{0.175}$ мм. Feed is taken based on recommendations ***[1]*** $\boldsymbol{S} = (\boldsymbol{K_{OS}} = \mathbf{1.0}) \cdot (\boldsymbol{S}_{\text{рек}} = \mathbf{1.5}) = \mathbf{1.5}$ мм/об. According to ***[1],*** we assume the stability period of the reamer ***T =120 min*** . The cutting speed allowed by the stability of the tool is determined by the formula:

$$\boldsymbol{V} = \frac{\boldsymbol{C_v} \cdot \boldsymbol{D^q} \cdot \boldsymbol{K_v}}{\boldsymbol{T^m} \cdot \boldsymbol{S^Y} \cdot \boldsymbol{h^x}}\ \text{м/хв}$$

where ***C_v=10.5*** , ***q =0.3*** , ***y =0.65*** , ***m =0.4*** , ***x = 0.2 [1]*** .

Total correction factor

$$\boldsymbol{K_v} = \boldsymbol{K}_{\text{м}\boldsymbol{v}} \boldsymbol{K}_{\text{п}\boldsymbol{v}} \boldsymbol{K}_{\boldsymbol{иv}} (\boldsymbol{K_{iv}} = \mathbf{1.0})$$

For the given conditions: $\boldsymbol{K_V = K_{\text{м}v}K_{\text{п}v}K_{\text{и}v}K_{iv} = 1.0\left(^{750}/_{490}\right)^{-0.9} \cdot 0.8 \cdot 1.0 =}$ $\boldsymbol{0.54}$, *[1]* .

Therefore:

$$\boldsymbol{V = \frac{10.5 \cdot 49.6^{0.3} \cdot 0.54}{120^{0.4} \cdot 1.5^{0.65} \cdot 0.175^{0.2}} = 2.93}\ \text{м/хв}$$

The calculated spindle speed that the reamer stability allows is:

$$\boldsymbol{n_i = \frac{1000V_i}{\pi D} = \frac{1000 \cdot 2.93}{\pi \cdot 49.95} = 18.67}\ \text{об/хв}$$

We assume ***n = 19 rpm*** and ***v = 2.98 m/min*** .

Torque according to the formula:

$$\boldsymbol{M_{\text{кр}} = \frac{C_p \cdot h^x \cdot (s/z)^y \cdot D \cdot z}{2 \cdot 100} = \frac{67 \cdot 0.175^{1.2} \cdot (1.5/6)^{0.65} \cdot 49.95 \cdot 6}{2 \cdot 100} = 5.03}\ \text{Н} \cdot \text{м}$$

Axial force:

$$\boldsymbol{P_{\text{о}} = 10 \cdot C_p \cdot h^x \cdot s^y \cdot \left(K_p = \left(\frac{\sigma_{\text{в}}}{750}\right)^n = \left(\frac{490}{750}\right)^{0.75}\right) = 10 \cdot 67 \cdot 0.175^{1.2} \cdot 1.5^{0.65} \cdot 0.726}$$
$$\boldsymbol{= 78.2}\ \text{Н}$$

Cutting power:

$$\boldsymbol{N = \frac{M_{\text{кр}} \cdot n}{9750} = \frac{5.03 \cdot 19}{9750} = 9.8}\ \text{Вт}$$

the less power on the machine spindle.

Finally, for reaming the exact hole ***Ø50H7,*** we take: ***h=0.175mm*** ; ***S*** $_{rev}$ ***=1.5mm/rev*** ; ***S*** $_{min}$ ***=28. 5mm/min*** ; ***n= 19 rev/min*** ; ***V=2.98 m /min*** ; ***P*** $_{o}$ ***= 78.2H*** ; ***N =9.8 W*** , ***M*** $_{KR}$ ***= 5.03N m*** .

Calculation of cutting modes for fine reaming of a Ø50H7 hole

Initial data: processed material – ***steel 30L*** ; equipment – horizontal milling machine with CNC ***Haas*** model ***EC -400*** ; tool – reamer ***Ø50H7*** with insert knives made of high-speed steel ***P6M5*** , ***z =6*** , main angle in plan ***ϕ=45°*** (***ream 2364-0349 H7 GOST 883-80***).

Depth of cut when reaming$\boldsymbol{h = {}^{(D_{\text{тонке}} - D_{\text{точне}})}/_{2} = {}^{(50.025 - 49.95)}/_{2} =}$

$\boldsymbol{= 0.075}$ ммWe accept submissions based on recommendations ***[1]*** $\boldsymbol{S = (K_{OS} = 0.7) \cdot (S_{\text{рек}} = 1.5) =}$

$= \mathbf{1.05}$ мм/об. According to ***[1],*** we assume the stability period of the reamer ***T =120 min*** . The cutting speed allowed by the stability of the tool is determined by the formula:

$$V = \frac{C_v \cdot D^q \cdot K_v}{T^m \cdot S^Y \cdot h^x}\ \text{м/хв}$$

where ***C_v=10.5*** , ***q =0.3*** , ***y =0.65*** , ***m =0.4*** , ***x = 0.2 [1]*** .

Total correction factor

$$K_v = K_{\text{м}v} K_{\text{п}v} K_{\text{и}v} (K_{iv} = 1.0)$$

For the given conditions: $K_V = K_{\text{м}v} K_{\text{п}v} K_{\text{и}v} K_{iv} = 1.0\left({}^{750}\!/_{490}\right)^{-0.9} \cdot 0.8 \cdot 1.0 = 0.54$, ***[1]*** .

Therefore:

$$V = \frac{10.5 \cdot 50.025^{0.3} \cdot 0.54}{120^{0.4} \cdot 1.05^{0.65} \cdot 0.075^{0.2}} = 4.39\ \text{м/хв}$$

The calculated spindle speed that the reamer stability allows is:

$$n_i = \frac{1000 V_i}{\pi D} = \frac{1000 \cdot 4.39}{\pi \cdot 50.025} = 27.93\ \text{об/хв}$$

We assume ***n = 28 rpm*** and ***v = 4.4 m/min*** .

Torque according to the formula:

$$M_{\text{кр}} = \frac{C_p \cdot h^x \cdot (s/z)^y \cdot D \cdot z}{2 \cdot 100} = \frac{67 \cdot 0.075^{1.2} \cdot (1.05/6)^{0.65} \cdot 50.025 \cdot 6}{2 \cdot 100} = 1.45\ \text{Н} \cdot \text{м}$$

Axial force:

$$P_{\text{о}} = 10 \cdot C_p \cdot h^x \cdot s^y \cdot \left(K_p = \left(\frac{\sigma_{\text{в}}}{750}\right)^n = \left(\frac{490}{750}\right)^{0.75} \right) = 10 \cdot 67 \cdot 0.075^{1.2} \cdot 1.05^{0.65} \cdot 0.726 = 22\ \text{Н}$$

Cutting power:

$$N = \frac{M_{\text{кр}} \cdot n}{9750} = \frac{1.45 \cdot 28}{9750} = 4\ \text{Вт}$$

the less power on the machine spindle.

Finally, for reaming a precise hole ***Ø50H7,*** we take: ***h=0.075mm*** ; ***S_{rev}=1.05mm/rev*** ; ***n= 28 rev/min*** ; ***V=4. 4 m/min*** ; P ***$_{o}$ = 22H ;*** N = ***4 W*** , ***M_{KR}=1.45N m .***

Calculation of cutting modes for drilling a hole Ø25H9

Initial data: material to be processed – ***30L steel ; equipment – Haas*** EC ***- 400*** CNC horizontal milling machine ; tool – ***Ø24.75 twist drill*** made of high-speed steel ***R6M5*** (***Drill 2301-3651-A1 GOST 10903-77***); drill sharpening form – ***H*** (normal, single).

Depth of cut when drilling $\boldsymbol{h = {}^{D}/_{2} = {}^{24.75}/_{2} = 12.375}$ мм. Feed is taken based on recommendations ***[1]*** $\boldsymbol{S = (K_{OS} = 0.5) \cdot \left(S_{\text{рек}} = 0.49 \div 0.58\right) = 0.5 \cdot 0.49 = 0.245}$мм/об, where $\boldsymbol{K_{OS} = 0.5}$**is** the correction factor for higher quality for the next reaming. According to ***[1],*** we assume the drill stability period ***T =45 min*** . The cutting speed allowed by the tool stability is determined by the formula:

$$\boldsymbol{V = \frac{C_v \cdot D^q \cdot K_v}{T^m \cdot S^Y}} \text{ м/хв}$$

where $\boldsymbol{C_v}$***=9.8*** , ***q =0.40*** , ***y =0.50*** , ***m =0.2 0 [1]*** .

Total correction factor

$$\boldsymbol{K_v = K_{\text{м}v} K_{\text{п}v} K_{\text{и}v} (K_{iv} = 1.0)}$$

For the given conditions: $\boldsymbol{K_V = K_{\text{м}v} K_{\text{п}v} K_{\text{и}v} K_{iv} = 1.0\left({}^{750}/_{490}\right)^{-0.9} \cdot 0.8 \cdot 1.0 = 0.54}$, ***[1]*** .

Therefore:

$$\boldsymbol{V = \frac{9.8 \cdot 24.75^{0.4} \cdot 0.54}{45^{0.2} \cdot 0.245^{0.5}} = 18.023} \text{ м/хв}$$

Estimated spindle speed that the drill stability allows:

$$\boldsymbol{n_i = \frac{1000V_i}{\pi D} = \frac{1000 \cdot 18.023}{\pi \cdot 24.75} = 231.793} \text{ об/хв}$$

We take ***n =232 rpm*** , ***V =18.039m/min*** .

Torque according to the formula:

$$\boldsymbol{M_{\text{кр}} = 10 \cdot C_M \cdot D^q \cdot s^y \cdot \left(K_p = \left(\frac{\sigma_{\text{в}}}{750}\right)^n = \left(\frac{490}{750}\right)^{0.75}\right)}$$
$$\boldsymbol{= 10 \cdot 0.0345 \cdot 24.75^{2.0} \cdot 0.245^{0.8} \cdot 0.726 == 49.8} \text{ Н} \cdot \text{м}$$

Axial force:

$$\boldsymbol{P_{\text{о}} = 10 \cdot C_p \cdot D^q \cdot s^y \cdot \left(K_p = \left(\frac{\sigma_{\text{в}}}{750}\right)^n = \left(\frac{490}{750}\right)^{0.75}\right)}$$
$$\boldsymbol{= 10 \cdot 68 \cdot 24.75^{1.0} \cdot 0.245^{0.7} \cdot 0.726 == 4565}\text{Н}$$

Cutting power:

$$N = \frac{M_{кр} \cdot n}{9750} = \frac{49.8 \cdot 232}{9750} = 1.18 \text{ кВт}$$

the less power on the machine spindle.

Finally, for drilling a hole ***Ø25H9*,** we take: ***h=12.375mm*** ; ***S*** $_{rev}$ ***=0.245mm/rev*** ; ***S*** $_{min}$ ***=56.84mm/min*** ; ***n=232rev/min*** ; ***V=18.039m/min*** ; ***P*** $_o$ ***= 4565H*** ; ***N = 1.18kW ; M*** $_{KR}$ ***= 49.8N m*** .

Calculation of cutting modes for precise reaming of a Ø25H9 hole

Initial data: material to be machined – ***30L steel ; equipment – Haas*** EC ***- 400*** CNC horizontal milling machine ; tool – ***Ø25 reamer*** made of high-speed steel ***R6M5*** , ***z =8*** , main angle in plan ***ϕ =15*** ° (***Reamer 2363-3472 H9 GOST 1672-80***).

Depth of cut when turning $h = {(D_{разв} - D_{отв})}/{2} = {(25.052 - 24.75)}/{2} = 0.151$ мм. Feed is taken based on recommendations ***[1]*** $S = (K_{OS} = 0.8) \cdot (S_{рек} = 1.0) = 0.8$ мм/об., and, taking into account the requirement given there, that the feed when reaming blind holes does not exceed the mark $0.2 \div 0.5$ – we finally accept the feed ***S =0.2 mm/rev*** . According to ***[1]*** we accept the reaming stability period ***T =40 min*** . The cutting speed, which is allowed by the tool stability, is determined by the formula:

$$V = \frac{C_v \cdot D^q \cdot K_v}{T^m \cdot S^Y \cdot h^x} \text{ м/хв}$$

where C_v***=10.5*** , ***q =0.3*** , ***y =0.65*** , ***m =0.4*** , ***x =0.2 [1]*** .

Therefore:

$$V = \frac{10.5 \cdot 25.052^{0.3} \cdot 0.54}{40^{0.4} \cdot 0.2^{0.65} \cdot 0.151^{0.2}} = 14 \text{ м/хв}$$

The calculated spindle speed that the reamer stability allows is:

$$n_i = \frac{1000V_i}{\pi D} = \frac{1000 \cdot 14}{\pi \cdot 25.052} = 178 \text{ об/хв}$$

Torque according to the formula:

$$M_{кр} = \frac{C_p \cdot h^x \cdot (s/z)^y \cdot D \cdot z}{2 \cdot 100} = \frac{67 \cdot 0.151^{1.2} \cdot (0.2/8)^{0.65} \cdot 25.052 \cdot 8}{2 \cdot 100} = 0.63 \text{ Н} \cdot \text{м}$$

Axial force:

$$\boldsymbol{P}_{\text{o}} = \mathbf{10} \cdot \boldsymbol{C_p} \cdot \boldsymbol{h^x} \cdot \boldsymbol{s^y} \cdot \left(\boldsymbol{K_p} = \left(\frac{\boldsymbol{\sigma}_{\text{в}}}{\mathbf{750}}\right)^{\boldsymbol{n}} = \left(\frac{\mathbf{490}}{\mathbf{750}}\right)^{0.75} \right) = \mathbf{10 \cdot 67 \cdot 0.151^{1.2} \cdot 0.2^{0.65} \cdot 0.726} = \mathbf{17.67}\ \text{Н}$$

Cutting power:

$$\boldsymbol{N} = \frac{\boldsymbol{M}_{\text{кр}} \cdot \boldsymbol{n}}{\mathbf{9750}} = \frac{\mathbf{0.63 \cdot 178}}{\mathbf{9750}} = \mathbf{11.5}\ \text{Вт}$$

the less power on the machine spindle.

Finally, for reaming the exact hole ***Ø25H9,*** we take: ***h=0.151mm*** ; ***S*** $_{rev}$ ***=0.2mm/rev*** ; ***S*** $_{min}$ ***=35.6mm/min*** ; ***n=178rev/min*** ; ***V=14m/min*** ; ***P*** $_{o}$ ***= 17.67H*** ; ***N = 11.5W*** , ***M*** $_{KR}$ ***= 0.63N m*** .

Calculation of cutting modes for milling of L/M ledges

Initial data: the processed material is ***steel 30L*** ; equipment is a horizontal milling machine with a ***Haas CNC*** model ***EC -400*** ; tool is an end mill with a cylindrical shank equipped with helical carbide inserts ***Ø32*** , ***Z = 4*** (***GOST 20537-75***). Milling depth ***h = 14.5 mm*** , milling width – ***B = 10 mm*** . (End mill ***2223-0505 T15K6 GOST 20537-75)*** . Inserts ***36010*** according to ***GOST 25414-82*** .

According to ***[7, 1]*** we choose the feed per tooth of the milling cutter ***S*** $_{Z}$ ***= 0. 048 mm/tooth*** , per revolution – ***S*** $_{OB}$ ***= S*** $_{Z}$ ***· Z = 0.048 · 4 = 0.192 mm/rev*** .

We assign the milling cutter stability period ***T =120 min. [1, vol. 2, p. 290]*** .

The cutting speed allowed by the tool stability is calculated using the formula:

$$\boldsymbol{V_i} = \frac{\boldsymbol{C_V D^{q_v}}}{\boldsymbol{T^m h^{x_v} S_Z{}^{y_v} B^{u_v} Z^{p_v}}} \boldsymbol{K_V}\ \text{м/хв}$$

For the given conditions: $\boldsymbol{K_V} = \boldsymbol{K}_{\text{м}v}\boldsymbol{K}_{\text{п}v}\boldsymbol{K}_{\text{и}v} = \mathbf{1.0}\left({}^{\mathbf{750}}/_{\mathbf{490}}\right)^{\mathbf{1.0}} \cdot \mathbf{0.8} \cdot \mathbf{1.15} = \mathbf{1.4},$ ***[1, vol. 2, p. 282]*** .

Then

$$\boldsymbol{V_i} = \frac{\mathbf{234 \cdot 32^{0.44}}}{\mathbf{120^{0.37} 14.5^{0.24} 0.048^{0.26} 10^{0.1} 4^{0.13}}} \mathbf{1.4} = \mathbf{196.8765}\ \text{м/хв}$$

The calculated spindle speed that the stability of the milling cutter allows:

$$n_i = \frac{1000V_i}{\pi D} = \frac{1000 \cdot 196.8765}{\pi \cdot 32} = 1958 \text{ об/хв}$$

(after correcting the revolutions to an integer value, the cutting speed is ***V = 196.8396m / min***)

Circumferential cutting force in milling ***[1]*** :

$$P_Z = 10\frac{C_p h^{X_p} S_Z{}^{Y_p} B^{U_p} z}{D^{Q_p} n^{\omega_p}} K_p \text{ Н}$$

For these conditions:

$$P_Z = 10\frac{12.5 \cdot 14.5^{0.85} \cdot 0.048^{0.75} \cdot 10^{1.0} \cdot 4}{32^{0.73} \cdot 1958^{-0.13}}\left({}^{490}/_{750}\right)^{0.3} = 93.5 \text{ Н}$$

Torque on the machine spindle:

$$M_{\text{кр}} = \frac{P_z D}{2 \cdot 100} = \frac{93.5 \cdot 32}{2 \cdot 100} = 14.96 \text{ Н} \cdot \text{м}$$

Cutting power on the machine spindle:

$$N = \frac{P_z v}{1000 \cdot 60} = \frac{93.5 \cdot 196.84}{1000 \cdot 60} = 300 \text{ Вт}$$

Since the calculated power is less than the effective power of the machine (***N = 300W <Ne –14.9kW***), the milling speed will be limited only by the stability of the tool.

Finally, the milling mode of ***the L/M ledges*** is as follows: ***h=14.5mm*** ; ***S_Z =0.048mm/tooth*** ; ***S_{rev} =0.192mm/rev*** ; ***S_{min} =375.936mm/min*** ; ***n=1958rev/min*** ; ***V=196.84m/min*** ; ***P_Z=93.5H*** .

Calculation of cutting mode for milling of metal surfaces

Initial data: material to be machined – ***30L steel ; equipment – Haas*** EC ***- 400*** CNC horizontal milling machine ; tool – end mill with cylindrical shank ***Ø25*** , ***Z = 6*** (***GOST 17025-71***) made of high-speed steel ***P6M5*** . Milling depth ***h = 2mm*** , milling width – ***B = 25mm*** .

According to ***[7, 1],*** the feed per tooth of the milling cutter ***is S_Z= 0.07 mm/tooth*** , per revolution – ***S_{OB} = S_Z · Z = 0.07 · 6 = 0.42 mm/rev*** .

We assign a milling cutter stability period of ***T =90 min. [1, vol. 2, p. 290]*** .

The cutting speed allowed by the tool stability is calculated using the formula:

$$V_i = \frac{C_V D^{q_v}}{T^m h^{x_v} S_Z{}^{y_v} B^{u_v} Z^{p_v}} K_V = \frac{46.7 \cdot 25^{0.45}}{90^{0.33} 2^{0.5} 0.07^{0.5} 25^{0.1} 6^{0.1}} 1.4 = 102.08 \text{ м/хв}$$

The calculated spindle speed that the stability of the milling cutter allows:

$$n_i = \frac{1000 V_i}{\pi D} = \frac{1000 \cdot 102.08}{\pi \cdot 25} = 1300 \text{ об/хв}$$

(after correcting the revolutions to an integer value, the cutting speed is ***V = 102.1m/min***)

Circumferential cutting force in milling ***[1]*** :

$$P_Z = 10 \frac{C_p h^{X_p} S_Z{}^{Y_p} B^{U_p} Z}{D^{Q_p} n^{\omega_p}} K_p = 10 \frac{68.2 \cdot 2^{0.86} \cdot 0.07^{0.72} \cdot 25^{1.0} \cdot 6}{25^{0.86} \cdot 1300^{0}} \left({}^{490}\!/_{750} \right)^{0.3} = 1512 \text{Н}$$

Torque on the machine spindle:

$$M_{\text{кр}} = \frac{P_z D}{2 \cdot 100} = M_{\text{кр}} = \frac{1512 \cdot 25}{2 \cdot 100} = 189 \text{ Н} \cdot \text{м}$$

Cutting power on the machine spindle:

$$N = \frac{P_z v}{1000 \cdot 60} = \frac{1512 \cdot 102.1}{1000 \cdot 60} = 2.6 \text{ кВт}$$

Since the calculated power is less than the effective power of the machine (***N = 2.6 kW <Ne –14.9 kW***), the milling speed will be limited only by the stability of the tool.

Estimated value of the minute feed of the table with the workpiece

$$S_{\text{хв}} = S_{\text{об}} \cdot n = 0.42 \cdot 1300 = 546 \text{ мм/хв}$$

The selected machine allows for stepless adjustment of spindle speed and feed rates. In addition, the obtained values of spindle speed and feed rate belong to the operating range of the machine, so we finally accept the calculated speed values.

Finally, the milling mode of the surface of ***the Z/Z*** is as follows: ***h=2mm*** ; ***S_Z =0.07mm/tooth*** ; ***S_{rev} =0.42mm/rev*** ; ***S_{min} =546mm/min*** ; ***n=1300rev/min*** ; ***V=102.1m/min*** ; ***P_Z =1512H*** .

Determination of cutting modes by analog method

The cutting mode is determined according to the tables in the following sequence ***[4]*** : we select the tool and the material of its cutting part; for technological reasons, we select the cutting depth ***h*** , ***mm*** ; focusing on the table values, we determine the feed $\boldsymbol{S}_{\boldsymbol{0}}$, ***mm*** per revolution of the workpiece or tool, or $\boldsymbol{S}_{\boldsymbol{Z}}$, ***mm*** per tooth; the recommended cutting speed is selected according to the tables, and the machine spindle rotation frequency ***n is calculated from it*** ; based on ***n , V*** and $\boldsymbol{S}_{\boldsymbol{XV}}$ are determined . The results of the calculations and selection of cutting modes are given in the table (Appendix 3).

Determination of time standards

According to ***[6, 7],*** the norm of artificial calculation time spent on performing an operation in serial production is calculated by the formula:

$$\boldsymbol{T}_{\text{ш.к}} = \boldsymbol{T}_{\text{ш}} + \frac{\boldsymbol{T}_{\text{п.з}}}{\boldsymbol{n}} = \boldsymbol{T}_{\text{о}} + \boldsymbol{k} \cdot \boldsymbol{T}_{\text{д}} + \boldsymbol{T}_{\text{обс}} + \boldsymbol{T}_{\text{вл}} + \frac{\boldsymbol{T}_{\text{п.з}}}{\boldsymbol{n}}, \text{хв}$$

where $\boldsymbol{T}_{\boldsymbol{W}}$ – artificial time rate, min ***;*** $\boldsymbol{T}_{\boldsymbol{P.Z}}$ – standard preparatory and final time for processing a batch of blanks, min; ***n*** – number of blanks in a batch, pcs; $\boldsymbol{T}_{\boldsymbol{O}}$, $\boldsymbol{T}_{\boldsymbol{D}}$ – respectively, main and auxiliary time, min; $\boldsymbol{T}_{\boldsymbol{OBS}}$ – time for servicing the workplace, min; $\boldsymbol{T}_{\boldsymbol{VL}}$ – own break time for personal needs, min, ***k*** – correction factor for auxiliary time, ***k = 1.0 [6, vol. 1, p. 50]*** .

The basic time for performing one transition is determined by the formula:

$$\boldsymbol{T}_{0_i} = \sum \frac{\boldsymbol{L}_i}{\boldsymbol{S}_{\text{хв}\,i}} = \sum \frac{\boldsymbol{l}_i + \boldsymbol{l}_{\text{вр}\,i} + \boldsymbol{l}_{\text{пер}\,i}}{\boldsymbol{S}_{\text{хв}\,i}}$$

where ***L*** is the estimated machining length, i.e. the total length of the tool stroke, which consists of the length of the machined surface ***l*** , the cutting length $\boldsymbol{l}_{\boldsymbol{BP}}$ and the tool travel length $\boldsymbol{l}_{\boldsymbol{PER}}$, mm. The values of $\boldsymbol{l}_{\boldsymbol{BP}}$ and $\boldsymbol{l}_{\boldsymbol{PER}}$ are selected according to ***[7]*** .

The rate of auxiliary time $\boldsymbol{T}_{\boldsymbol{D}}$, spent on the actions of the machine operator, which ensure the direct performance of the main technological work, is determined by ***[17, 18, 19]*** .

The values of $\boldsymbol{T}_{\boldsymbol{OBS}}$ and $\boldsymbol{T}_{\boldsymbol{VL}}$ are taken as a percentage of the operational ($\boldsymbol{T}_{\boldsymbol{OP}} = \boldsymbol{T}_{\boldsymbol{O}} + \boldsymbol{T}_{\boldsymbol{D}}$) time according to the recommendations ***[17, 18, 19]*** , and the value of $\boldsymbol{T}_{\boldsymbol{PZ}}$ is determined according to the standards ***[17, 18, 19]*** .

Calculation of the time norm for performing operation 005

Initial data: cutting modes (Appendix 3); processed material – ***30L steel ; equipment – Haas*** EC ***- 400*** CNC horizontal milling machine ; device – single-seat.

We sequentially calculate the main processing time by transitions (in parallel, supplementing the cutting mode tables (Appendix 3) and filling in the route and operational maps):

Milling ***A*** :

$$\boldsymbol{T}_{01}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{154+23}}{\mathbf{836.4}}=\mathbf{0.2313}\text{хв}=\mathbf{13.878}\text{сек.}$$

Rough milling ***K*** :

$$\boldsymbol{T}_{02}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{154+23}}{\mathbf{1680}}=\mathbf{0.1054}\text{хв}=\mathbf{6.5}\text{сек.}$$

Semi-clean milling ***K*** :

$$\boldsymbol{T}_{03}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{177}}{\mathbf{1075}}=\mathbf{0.165}\text{хв}=\mathbf{10}\text{сек.}$$

Milling of ledges ***L/M*** :

$$\boldsymbol{T}_{04}=\mathbf{4}\cdot\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\mathbf{4}\cdot\frac{\mathbf{34+16}}{\mathbf{375.976}}=\mathbf{0.532}\text{хв}=\mathbf{32}\text{сек.}$$

Rough milling of a groove ***20N9*** :

$$\boldsymbol{T}_{05}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{70+23}}{\mathbf{107.46}}=\mathbf{0.8643}\text{хв}=\mathbf{51.858}\text{сек.}$$

Semi-clean slot milling ***20H9*** :

$$\boldsymbol{T}_{06}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{93}}{\mathbf{153.9}}=\mathbf{0.6043}\text{хв}=\mathbf{36.258}\text{сек.}$$

Finish milling of the groove ***20N9*** :

$$\boldsymbol{T}_{07}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{93}}{\mathbf{171.9}}=\mathbf{0.541}\text{хв}=\mathbf{32.46}\text{сек.}$$

Countersinking a hole ***Ø50H7*** :

$$\boldsymbol{T}_{08}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{110+24.5+3}}{\mathbf{437.5}}=\mathbf{0.314}\text{хв}=\mathbf{18.84}\text{сек.}$$

Precise reaming of a hole ***Ø50H7*** :

$$\boldsymbol{T}_{09}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{137.5}}{\mathbf{28.5}}=\mathbf{4.8245}\text{хв}=\mathbf{4}\text{хв }\mathbf{49}\text{сек.}$$

Reaming of thin holes ***Ø50H7*** :

$$\boldsymbol{T}_{010}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{137.5}}{\mathbf{29.4}}=\mathbf{4.67687}\text{хв}=\mathbf{4}\text{хв }\mathbf{41}\text{сек.}$$

Drilling a hole ***Ø20H9*** :

$$\boldsymbol{T}_{011}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{22+10}}{\mathbf{61.06}}=\mathbf{0.524}\text{хв}=\mathbf{31.5}\text{сек.}$$

Reaming of the hole ***Ø20H9*** :

$$\boldsymbol{T}_{012}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{22+25}}{\mathbf{44.4}}=\mathbf{1.05855}\text{хв}=\mathbf{63.5}\text{сек.}$$

Drilling a hole ***Ø25H9*** :

$$\boldsymbol{T}_{013}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{32}}{\mathbf{56.84}}=\mathbf{0.56298}\text{хв}=\mathbf{34}\text{сек.}$$

Reaming of the hole ***Ø25H9*** :

$$\boldsymbol{T}_{014}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{47}}{\mathbf{35.6}}=\mathbf{1.32}\text{хв}=\mathbf{79.5}\text{сек.}$$

Total basic time:

$$\mathrm{T}_0=\sum_{\boldsymbol{i}=\mathbf{1}}^{\mathbf{14}}\mathrm{T}_{0_{\boldsymbol{i}}}=\mathbf{16.3103}\text{хв}$$

To determine T_D, we enter all auxiliary work performed during operation ***010*** and, according to ***[19]*** , find the time spent on them (Table 2.7).

According to ***[19, p. 110]*** , the time for servicing the workplace $T_{OBS} = 3.5\%(T_O + T_D)$ and according to ***[19, p. 203]*** , $T_{VL} = 6\%(T_O + T_D)$.

The preparatory and final time for a batch of blanks ***[19]*** is ***20 minutes*** . As a result, the standard of artificial and calculation time spent on performing operation ***0 05*** is:

$$\boldsymbol{T}_{\text{ш.к}} = \boldsymbol{T}_{\text{ш}} + \frac{\boldsymbol{T}_{\text{п.з}}}{\boldsymbol{n}} = \left(\mathrm{T_O} + \mathrm{T_Д}\right)\left(\mathbf{1} + \frac{\mathbf{6 + 3.5}}{\mathbf{100}}\right) + \frac{\mathbf{20}}{\mathbf{80}} = (\mathbf{16.3103 + 1.54}) \cdot \mathbf{1.095} + \frac{\mathbf{1}}{\mathbf{4}} = \mathbf{19.8}, \text{хв}$$

Machine operator actions	***Time limit, min***
Clean the device from chips (with a brush)	***0.09***
Install and remove the workpiece (manually)	***0.15***
Fasten and unfasten workpieces	***2*0.5***
Time to complete transitions	***0.3***
In general	***1.54min=92.4sec***

Table 2.7 Auxiliary actions of the machine operator

Let's normalize for operation ***010*** :

Milling ***E*** :

$$\boldsymbol{T}_{01} = \frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}} = \frac{\mathbf{90 + 23}}{\mathbf{1595}} = \mathbf{0.071}\text{хв} = \mathbf{4.5}\text{сек.}$$

Milling ***D*** :

$$\boldsymbol{T}_{02} = \frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}} = \frac{\mathbf{113}}{\mathbf{509.2}} = \mathbf{0.222}\text{хв} = \mathbf{13.5}\text{сек.}$$

Milling of ***W/C*** :

$$\boldsymbol{T}_{03} = \mathbf{2} \cdot \frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}} = \mathbf{2} \cdot \frac{\mathbf{98}}{\mathbf{546}} = \mathbf{2} \cdot \mathbf{0.179487}\text{хв} = \mathbf{0.36}\text{хв} = \mathbf{21.5}\text{сек.}$$

Cutting a ***5mm slot*** :

$$\boldsymbol{T}_{\mathbf{0}4}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{30+48}}{\mathbf{50.7}}=\mathbf{1.5384}\text{хв}=\mathbf{92.3}\text{сек.}$$

Surface milling ***H*** :

$$\boldsymbol{T}_{05}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{40+10}}{\mathbf{105.984}}=\mathbf{0.472}\text{хв}=\mathbf{28.5}\text{сек.}$$

Surface milling ***O*** previous:

$$\boldsymbol{T}_{06}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{40+10}}{\mathbf{105.984}}=\mathbf{0.472}\text{хв}=\mathbf{28.5}\text{сек.}$$

Surface milling ***O*** final:

$$\boldsymbol{T}_{07}=\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\frac{\mathbf{40+10}}{\mathbf{105.984}}=\mathbf{0.472}\text{хв}=\mathbf{28.5}\text{сек.}$$

Centering of holes for ***M10-7N thread*** :

$$\boldsymbol{T}_{08}=\mathbf{5}\cdot\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\mathbf{5}\cdot\frac{\mathbf{6.45}}{\mathbf{228}}=\mathbf{0.14145}\text{хв}=\mathbf{8.5}\text{сек.}$$

Drilling holes for ***M10-7N thread*** :

$$\boldsymbol{T}_{09}=\mathbf{5}\cdot\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\mathbf{5}\cdot\frac{\mathbf{34}}{\mathbf{124.15}}=\mathbf{1.3693}\text{хв}=\mathbf{82.5}\text{сек.}$$

Countersinking two holes ***Ø12/20*** :

$$\boldsymbol{T}_{010}=\mathbf{2}\cdot\frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}}=\mathbf{2}\cdot\frac{\mathbf{14.5}}{\mathbf{48.139}}=\mathbf{0.603}\text{хв}=\mathbf{36.5}\text{сек.}$$

Countersinking chamfers ***1x45 °*** :

$$\boldsymbol{T}_{011} = \mathbf{5} \cdot \frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}} = \mathbf{5} \cdot \frac{\mathbf{1+17}}{\mathbf{24.5}} = \mathbf{3.674}\text{хв} = \mathbf{220.5}\text{сек.}$$

Thread cutting ***M10-7N*** :

$$\boldsymbol{T}_{012} = \mathbf{5} \cdot \frac{\boldsymbol{L}}{\boldsymbol{S}_{\text{хв}}} = \mathbf{5} \cdot \frac{\mathbf{34}}{\mathbf{486}} = \mathbf{0.35}\text{хв} = \mathbf{21}\text{сек.}$$

Total basic time:

$$\text{Т}_{\text{О}} = \sum_{\boldsymbol{i}=\mathbf{1}}^{\mathbf{12}} \text{Т}_{\text{О}_{\boldsymbol{i}}} = \mathbf{9.74515}\text{хв}$$

As a result, the rate of artificial calculation time spent on performing operation ***0 10*** is:

$$\boldsymbol{T}_{\text{ш.к}} = \boldsymbol{T}_{\text{ш}} + \frac{\boldsymbol{T}_{\text{п.з}}}{\boldsymbol{n}} = \left(\text{Т}_{\text{О}} + \text{Т}_{\text{Д}}\right)\left(\mathbf{1} + \frac{\mathbf{6+3.5}}{\mathbf{100}}\right) + \frac{\mathbf{20}}{\mathbf{80}} = (\mathbf{9.74515} + \mathbf{1.54}) \cdot \mathbf{1.095} + \frac{\mathbf{1}}{\mathbf{4}} = \mathbf{12.61},\text{хв}$$

Finally, all calculations performed and arguments presented are drawn up in the form of route and operational (Appendix 2) maps, in accordance with all the rules for filling out technological documentation.

3. Design section

3.1. Design of the device for operation 005

Description and principle of operation of the device

According to the developed technological process, the workpiece is fixed with the untreated surfaces ***Ø70*** and ***V*** / ***G*** in the prisms, basing the specified surfaces in the prisms through the clamping machine tool. Also, the workpiece is centered along the plane of symmetry.

Prisms will be used non-standard. For diameter ***Ø70*** , a prism with a deep slot (possibly prefabricated) with a slot width of ≈ ***40-45*** mm will be used, which will allow installing ***Ø70*** workpieces symmetrically relative to the plane ***F*** (the plane of the separation of the flasks). This prism will remain stationary during processing, providing two points of support for basing.

The workpiece is secured for reliable processing by a second prism that “clamps” the surfaces ***B*** / ***G.*** Serving as a directional clamping device, as already noted in previous sections, this prism will leave the workpiece with three degrees of freedom.

Since the processing will be carried out on a CNC machine and a fourth, additional axis will be used, in order to avoid entanglement of hydraulic or pneumatic pipes during the operation of the fourth axis of the machine, the device will be operated by human power. By tightening the nut, the wedge clamping mechanism ***7015-0011 GOST 13153-67 will be activated*** , which will set a special prism in motion, thanks to which the workpiece will be fixed.

The workpiece will be centered on the axis of symmetry using a plunger self-centering mechanism.

The device will be mounted on a universal assembly device ***USP-12*** . Using a unified kit will reduce the cost of the device itself.

Power calculation of the device

Calculation of self-centering wedge-plunger mechanism

When performing operation ***005,*** the most unfavorable conditions for the operation of the machine tool occur when drilling a hole ***Ø25H9 , when the value of the axial*** $_{cutting}$ force reaches ***Po =4565H*** .

Assuming that the maximum force that a machine operator can apply when tightening a screw is ***150N [10]*** , we will calculate the maximum possible force ***W*** with which the screw will act on the plungers.

Because:

$$P = \frac{W \cdot r_{\text{СЕР}} \cdot \tan(\varphi_{\text{ПР}} + \psi) + M_{\text{ТЕР}}}{L} \ \text{Н}$$

where $M_{\text{ТЕР}}$– friction moment on the body of the plunger mandrel of the bolt with thread diameter ***d = 12 mm*** and the diameter of the surface on the end of the cap $D = 16.6 \div 18$мм (***D =0.018m*** – turnkey size for this bolt), which is equal to:

$$M_{\text{ТЕР}} = \frac{1}{3} \cdot W \cdot f \frac{D^3 - d^3}{D^2 - d^2} \ \text{Н} \cdot \text{м}$$

given is the friction angle, which takes into account the triangular thread profile: $\varphi_{\text{ПР}} = 3°$, $r_{\text{СЕР}} = 0.0054315$м– average thread diameter ***M12*** , $L = 0.3$м– length of the wrench handle, $f = 0.15$– friction coefficient. Thread lead angle with pitch $P_{\text{РІЗІ}}$, and outer diameter $D_{\text{РІЗІ}}$:

$$\psi = arctan\left(\frac{P_{\text{РІЗІ}}}{\pi \cdot D_{\text{РІЗІ}}}\right) = arctan\left(\frac{0.00175}{\pi \cdot 0.012}\right) = 2.657773°$$

So, for the force ***W,*** we can say:

$$W = \frac{P \cdot L}{r_{\text{СЕР}} \cdot \tan(\varphi_{\text{ПР}} + \psi) + \frac{1}{3} \cdot f \frac{D^3 - d^3}{D^2 - d^2}} \ \text{Н}$$

$$W = \frac{150 \cdot 0.3}{0.0054315 \cdot \tan(5.657773°) + \frac{0.15}{3} \cdot \frac{0.018^3 - 0.012^3}{0.018^2 - 0.012^2}} = 26820\text{Н}$$

Regarding the self-centering wedge-plunger mechanism, then the required drive thrust force should be ***[10]*** :

$$W = (2 \cdot Q' + F) \cdot \frac{\tan(\frac{\alpha}{2} + \varphi_1)}{1 - \tan(\frac{\alpha}{2} + \varphi_1) \cdot \tan \varphi_3}$$

from here:

$$2 \cdot Q' = W \cdot \frac{1 - \tan\left(\frac{\alpha}{2} + \varphi_1\right) \cdot \tan \varphi_3}{\tan\left(\frac{\alpha}{2} + \varphi_1\right)} - F$$

$$2 \cdot Q' = 26820 \cdot \frac{1 - \tan(15° + 5.71°) \cdot \tan 5.71°}{\tan(15° + 5.71°)} - 200 = 66716\text{Н}$$

where$\boldsymbol{\varphi_1}$ – friction angle between the plunger and the wedge, $\boldsymbol{\varphi_3}$– friction angle between the plunger and the body ($\boldsymbol{\varphi_2}$– the friction angle between the wedge and the body in the self-centering mechanism is zero), $\boldsymbol{F}$ – total force, with which the spring pulls back the plungers, $\boldsymbol{Q'}$is the force acting on the workpiece. Again, we assume $\boldsymbol{\varphi_1 = \varphi_2 = 5.71°}$, the angle of the double-sided wedge $\boldsymbol{\alpha = 30°}$.

Therefore:

$$\mathbf{2 \cdot \boldsymbol{Q'} = 26820 \cdot \frac{1 - \tan(15° + 5.71°) \cdot \tan 5.71°}{\tan(15° + 5.71°)} - 200 = 66716}\text{H}$$

$$\mathbf{\boldsymbol{Q'} = 33358}\text{H}$$

Let's find the safety factor $\boldsymbol{K = K_0 \cdot K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_6 = 3.978}$**-** the reserve factor, where $\boldsymbol{K_0 = 1.5}$is the guaranteed reserve factor,$\boldsymbol{K_1 = 1.2}$ – coefficient of the state of the technological base (draft),$\boldsymbol{K_2 = 1.7}$ – takes into account tool wear ***[1, vol. 2, p . 292]*** ,$\boldsymbol{K_3 = 1.0}$ – coefficient, which takes into account the impact nature of the load on the tool, $\boldsymbol{K_4 = 1.3}$– for mechanisms with a manual drive, this coefficient takes into account the stability of the power drive, $\boldsymbol{K_5 = 1.0}$– characterizes clamping mechanisms with a manual drive ($\boldsymbol{K_5 = 1.0}$ provided there is a convenient drive, $\boldsymbol{K_5 = 1.2}$ if not convenient),$\boldsymbol{K_6 = 1.0}$ – takes into account the certainty of the location of the reference points ***[10, p . 34]*** . The safety technology of machine tools requires using a safety factor value not less than that, $\boldsymbol{K = 2.5}$and the calculated factor fully satisfies this requirement.

Then the value of the axial cutting force, which *must* be taken into account $\boldsymbol{K \cdot P_O = 3.978 \cdot 4565 = 18159.57}$H. It is clear that with the force achievable in the plunger pair $\boldsymbol{Q' = 33358}$H, neither the displacement of the workpiece during drilling nor the rotation in the plane of the separation of the flasks with the "opening" of the prisms will occur and we really have the right to say that the plunger *bases* workpiece along the plane of symmetry (Fig. 3.1).

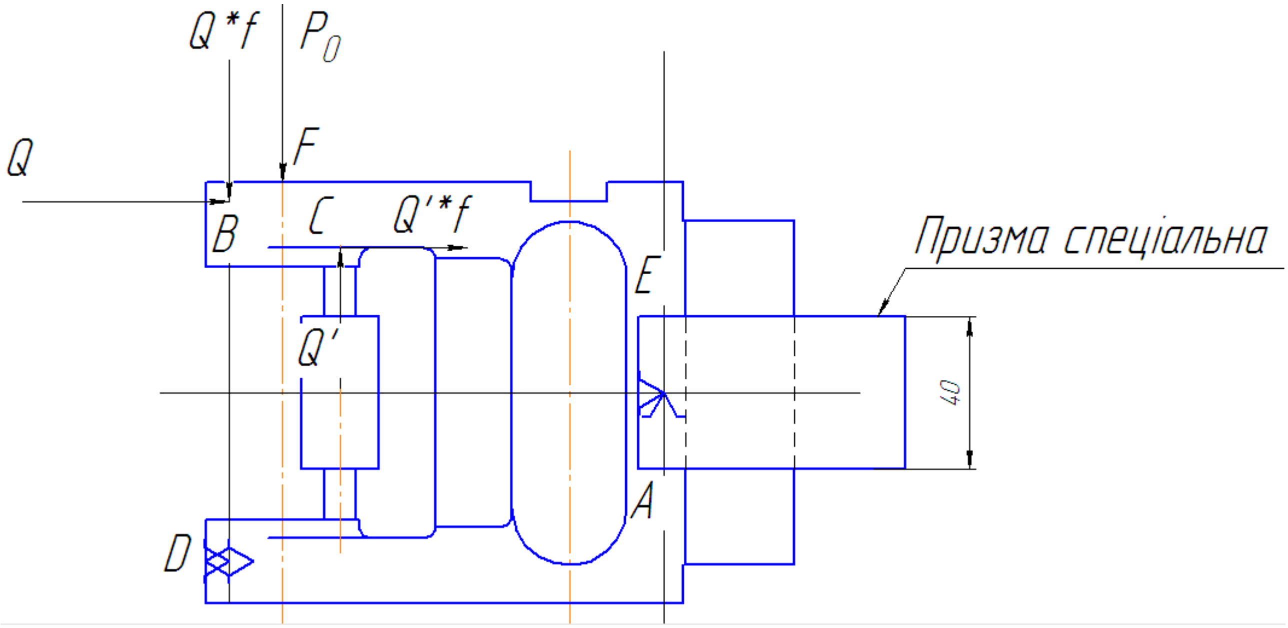


Figure 3.1 Drilling force diagram

Calculation of the wedge mechanism

It was previously calculated that when performing operation ***005,*** other The largest values of cutting forces and moments occur: when countersinking a hole ***Ø50H7*** – where the value of the moment of cutting forces is $\boldsymbol{M_{KP}=34\text{Нм}}$, when milling a plane ***A*** (circumferential cutting force, equal to $\boldsymbol{P_{Z}=757H}$) and the moment of cutting forces when drilling a hole ***Ø25H9*** – $\boldsymbol{M_{KR}=49.8N\ m}$. It is necessary to carry out calculations separately for both moments of cutting forces (countersinking, drilling), because the geometric, and with them the force parameters of the problem for different axes of rotation of the body: ***relative*** to the axis ***B*** and relative to the axis of the hole ***Ø25N9 -*** will be different, and therefore it is impossible to take a larger moment for calculations, neglecting the smaller one.

1. Let us formulate the equilibrium equation (see Fig. 3.2) for countersinking a hole ***Ø50H7*** with the effective cutting torque $\boldsymbol{M_{KP}=34\text{Нм}}$. Note that the vertical and horizontal components of the normal reactions of the prism are equal to $\boldsymbol{R_i}^{\text{верт.}} = \boldsymbol{R_i}^{\text{гор.}} = \boldsymbol{R_i^N}/\boldsymbol{\sqrt{2}}, \boldsymbol{i} = \boldsymbol{A}, \boldsymbol{B}, \boldsymbol{C}$; When compiling the equations, we will assume that the reaction of the prism at point ***D*** is zero, that is, the workpiece is “blown” from the support when it rotates around the axis ***E*** :

$$\begin{cases} \sum \boldsymbol{X} = \mathbf{0} \Leftrightarrow \dfrac{\mathbf{1}}{\sqrt{\mathbf{2}}} \cdot (\boldsymbol{R}_{\boldsymbol{A}}^{\boldsymbol{N}} \cdot (\mathbf{1} - \boldsymbol{f}_{\mathbf{1}}) - \boldsymbol{R}_{\boldsymbol{B}}^{\boldsymbol{N}} \cdot (\mathbf{1} - \boldsymbol{f}_{\mathbf{2}}) - \boldsymbol{R}_{\boldsymbol{C}}^{\boldsymbol{N}} \cdot (\mathbf{1} + \boldsymbol{f}_{\mathbf{3}})) = \mathbf{0} \\ \sum \boldsymbol{Y} = \mathbf{0} \Leftrightarrow \dfrac{\mathbf{1}}{\sqrt{\mathbf{2}}} \cdot (\boldsymbol{R}_{\boldsymbol{A}}^{\boldsymbol{N}} \cdot (\mathbf{1} + \boldsymbol{f}_{\mathbf{1}}) - \boldsymbol{R}_{\boldsymbol{B}}^{\boldsymbol{N}} \cdot (\mathbf{1} + \boldsymbol{f}_{\mathbf{2}}) + \boldsymbol{R}_{\boldsymbol{C}}^{\boldsymbol{N}} \cdot (\mathbf{1} - \boldsymbol{f}_{\mathbf{3}})) = \mathbf{0} \\ \sum \boldsymbol{M}_{\boldsymbol{E}} = \mathbf{0} \Leftrightarrow \boldsymbol{AE} \cdot \boldsymbol{R}_{\boldsymbol{A}}^{\boldsymbol{N}} \cdot (\boldsymbol{f}_{\mathbf{1}} \cdot \sin \mathbf{54}^{\circ} + \sin \mathbf{35.6}^{\circ}) + \boldsymbol{BE} \cdot \boldsymbol{R}_{\boldsymbol{B}}^{\boldsymbol{N}} \cdot \boldsymbol{f}_{\mathbf{2}} + \boldsymbol{CE} \cdot \boldsymbol{R}_{\boldsymbol{C}}^{\boldsymbol{N}} \cdot \boldsymbol{f}_{\mathbf{3}} = \boldsymbol{K} \cdot \boldsymbol{M}_{\text{pi3}} \end{cases}$$

$\boldsymbol{f}_{\mathbf{1}}, \boldsymbol{f}_{\mathbf{2}}, \boldsymbol{f}_{\mathbf{3}}$ – friction coefficients, respectively, at points $\boldsymbol{A}$, $\boldsymbol{B}$ and $\boldsymbol{C}$.

Cramer's rule to solve . To simplify the calculations, we will assume that $\forall \boldsymbol{f}_{\boldsymbol{i}}: \boldsymbol{f}_{\boldsymbol{i}} = \mathbf{0.15}, \boldsymbol{i} = \mathbf{1}, \mathbf{2}, \mathbf{3}$. In this case, the matrix of the system has the form:

$$\begin{bmatrix} \mathbf{0.85}/\sqrt{\mathbf{2}} & -\mathbf{0.85}/\sqrt{\mathbf{2}} & -\mathbf{1.15}/\sqrt{\mathbf{2}} \\ \mathbf{1.15}/\sqrt{\mathbf{2}} & -\mathbf{1.15}/\sqrt{\mathbf{2}} & \mathbf{0.85}/\sqrt{\mathbf{2}} \\ \mathbf{0.09} \cdot (\sin \mathbf{54}^{\circ} \cdot \mathbf{0.15} + \sin \mathbf{35.6}^{\circ}) & \mathbf{0.035} \cdot \mathbf{0.15} & \mathbf{0.035} \cdot \mathbf{0.15} \end{bmatrix}$$

And its determinant is equal to:

$$\Delta = -\mathbf{0.0701}$$

Column of independent system members:

$$\boldsymbol{X} = \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \boldsymbol{K} \cdot \boldsymbol{M}_{\text{pi3}} \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{3.978} \cdot \mathbf{34} \end{bmatrix}$$

The argument matrices obtained by replacing the columns of coefficients of the corresponding unknown reactions with the column of independent terms have the form:

Argument matrix $\boldsymbol{R}_{\boldsymbol{A}}^{\boldsymbol{N}}$:

$$\begin{bmatrix} \mathbf{0} & -\mathbf{0.85}/\sqrt{\mathbf{2}} & -\mathbf{1.15}/\sqrt{\mathbf{2}} \\ \mathbf{0} & -\mathbf{1.15}/\sqrt{\mathbf{2}} & \mathbf{0.85}/\sqrt{\mathbf{2}} \\ \mathbf{3.978} \cdot \mathbf{34} & \mathbf{0.035} \cdot \mathbf{0.15} & \mathbf{0.035} \cdot \mathbf{0.15} \end{bmatrix}$$

Argument matrix $\boldsymbol{R}_{\boldsymbol{B}}^{\boldsymbol{N}}$:

$$\begin{bmatrix} \mathbf{0.85}/\sqrt{2} & \mathbf{0} & \mathbf{-1.15}/\sqrt{2} \\ \mathbf{1.15}/\sqrt{2} & \mathbf{0} & \mathbf{0.85}/\sqrt{2} \\ \mathbf{0.09\cdot(\sin 54^\circ\cdot 0.15+\sin 35.6^\circ)} & \mathbf{3.978\cdot 34} & \mathbf{0.035\cdot 0.15} \end{bmatrix}$$

Argument matrix $\boldsymbol{R_C^N}$*:*

$$\begin{bmatrix} \mathbf{0.85}/\sqrt{2} & \mathbf{-0.85}/\sqrt{2} & \mathbf{0} \\ \mathbf{1.15}/\sqrt{2} & \mathbf{-1.15}/\sqrt{2} & \mathbf{0} \\ \mathbf{0.09\cdot(\sin 54^\circ\cdot 0.15+\sin 35.6^\circ)} & \mathbf{0.035\cdot 0.15} & \mathbf{3.978\cdot 34} \end{bmatrix}$$

Their *determinants* are respectively equal to:

$$\Delta_A = \mathbf{-138.295}, \qquad \Delta_B = \mathbf{-138.295}, \qquad \Delta_C = \mathbf{0},$$

Then, according to ***Cramer's formula*** :

$$\boldsymbol{R_A^N} = \frac{\Delta_A}{\Delta} = \frac{\mathbf{-138.295}}{\mathbf{-0.0701}} = \mathbf{1973}\text{H}$$

$$\boldsymbol{R_B^N} = \frac{\Delta_B}{\Delta} = \frac{\mathbf{-138.295}}{\mathbf{-0.0701}} = \mathbf{1973}\text{H}$$

$$\boldsymbol{R_C^N} = \frac{\Delta_C}{\Delta} = \frac{\mathbf{0}}{\mathbf{-0.0701}} = \mathbf{0}\text{H}$$

Clamping force ***Q*** is equal to the sum of the horizontal components of the normal reaction of the support at point ***A*** and the friction force:

$$\boldsymbol{Q} = \frac{\mathbf{1973\cdot(1-0.15)}}{\sqrt{\mathbf{2}}} = \mathbf{1186}\text{H}$$

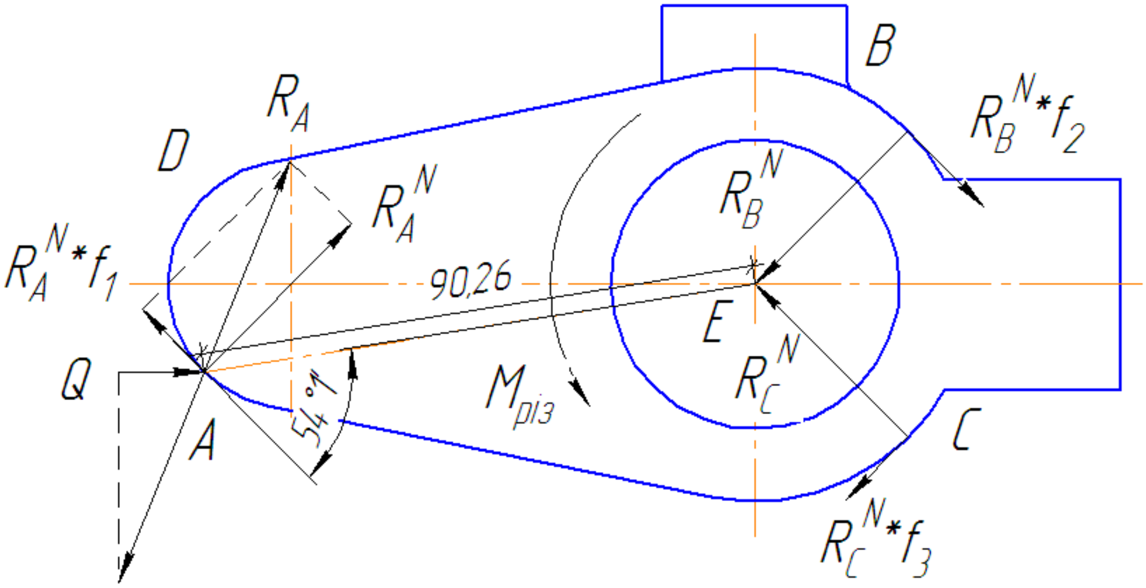


Figure 3.2 Force diagram when countersinking a hole Ø50H7

2. Let us draw up the equilibrium equation (see Fig. 3.3) for drilling a hole ***Ø25H9*** with the effective cutting torque ***$M_{КР}$=49.8Нм*** . Just as in the previous case, we note that the vertical and horizontal components of the normal reactions of the prism are equal to $\boldsymbol{R_i}^{\text{верт.}} = \boldsymbol{R_i}^{\text{гор.}} = \boldsymbol{R_i^N}/_{\sqrt{2}}, \boldsymbol{i = A, B, C}$ and when compiling the equations we will proceed from the assumption that the reaction of the prism at point ***D*** is zero, that is, the workpiece is "blown" from the support when it rotates around the axis ***E*** :

$$\begin{cases} \sum X = 0 \Leftrightarrow \dfrac{1}{\sqrt{2}} \cdot (R_A^N \cdot (1 + f_1) + R_B^N \cdot (1 - f_2) - R_C^N \cdot (1 - f_3)) = 0 \\ \sum Y = 0 \Leftrightarrow \dfrac{1}{\sqrt{2}} \cdot (R_A^N \cdot (1 - f_1) - R_B^N \cdot (1 + f_2) + R_C^N \cdot (1 + f_3)) = 0 \\ \sum M_E = 0 \Leftrightarrow AE \cdot R_A^N \cdot f_1 + BE \cdot R_B^N \cdot f_2 + CE \cdot R_C^N \cdot (f_3 \cdot \sin 59° + \sin 31°) = K \cdot M_{\text{різ}} \end{cases}$$

And, if $\forall \boldsymbol{f_i}: \boldsymbol{f_i = 0.15, i = 1, 2, 3}$, and the safety factor, as before: $\boldsymbol{K = 3.978}$, then the matrix of the system has the form:

$$\begin{bmatrix} 1.15/_{\sqrt{2}} & 0.85/_{\sqrt{2}} & -0.85/_{\sqrt{2}} \\ 0.85/_{\sqrt{2}} & -1.15/_{\sqrt{2}} & 1.15/_{\sqrt{2}} \\ 0.02 \cdot 0.15 & 0.02 \cdot 0.15 & 0.103 \cdot (0.15 \cdot \sin 59° + \sin 31°) \end{bmatrix}$$

And its determinant is equal to:

$$\Delta = -0.09845873$$

System independent data column:

$$\boldsymbol{X} = \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \boldsymbol{K} \cdot \boldsymbol{M}_{\text{pi3}} \end{bmatrix} = \begin{bmatrix} \mathbf{0} \\ \mathbf{0} \\ \mathbf{3.978 \cdot 49.8} \end{bmatrix}$$

The argument matrices obtained by replacing the columns of coefficients of the corresponding unknown reactions with the column of independent terms have the form:

Argument matrix $\boldsymbol{R_A^N}$:

$$\begin{bmatrix} \mathbf{0} & \mathbf{0.85}/\sqrt{\mathbf{2}} & \mathbf{-0.85}/\sqrt{\mathbf{2}} \\ \mathbf{0} & \mathbf{-1.15}/\sqrt{\mathbf{2}} & \mathbf{1.15}/\sqrt{\mathbf{2}} \\ \mathbf{3.978 \cdot 49.8} & \mathbf{0.02 \cdot 0.15} & \mathbf{0.103} \cdot (\mathbf{0.15} \cdot \boldsymbol{sin}\,\mathbf{59}^\circ + \boldsymbol{sin}\,\mathbf{31}^\circ) \end{bmatrix}$$

Argument matrix $\boldsymbol{R_B^N}$:

$$\begin{bmatrix} \mathbf{0.85}/\sqrt{\mathbf{2}} & \mathbf{0} & \mathbf{-1.15}/\sqrt{\mathbf{2}} \\ \mathbf{1.15}/\sqrt{\mathbf{2}} & \mathbf{0} & \mathbf{0.85}/\sqrt{\mathbf{2}} \\ \mathbf{0.02 \cdot 0.15} & \mathbf{3.978 \cdot 49.8} & \mathbf{0.103} \cdot (\mathbf{0.15} \cdot \boldsymbol{sin}\,\mathbf{59}^\circ + \boldsymbol{sin}\,\mathbf{31}^\circ) \end{bmatrix}$$

Argument matrix $\boldsymbol{R_C^N}$*:*

$$\begin{bmatrix} \mathbf{0.85}/\sqrt{\mathbf{2}} & \mathbf{-0.85}/\sqrt{\mathbf{2}} & \mathbf{0} \\ \mathbf{1.15}/\sqrt{\mathbf{2}} & \mathbf{-1.15}/\sqrt{\mathbf{2}} & \mathbf{0} \\ \mathbf{0.09 \cdot \sin 54^\circ \cdot 0.15} & \mathbf{0.035 \cdot 0.15} & \mathbf{3.978 \cdot 49.8} \end{bmatrix}$$

Their *determinants* are respectively equal to:

$$\Delta_{\boldsymbol{A}} = \mathbf{0}, \qquad \Delta_{\boldsymbol{B}} = \mathbf{-202.0614}, \qquad \Delta_{\boldsymbol{C}} = \mathbf{-202.0614},$$

Then, according to ***Cramer's formula*** :

$$\boldsymbol{R_A^N} = \frac{\Delta_{\boldsymbol{A}}}{\Delta} = \frac{\mathbf{0}}{\mathbf{-0.09845873}} = \mathbf{0}$$

$$\boldsymbol{R_B^N} = \frac{\Delta_{\boldsymbol{B}}}{\Delta} = \frac{\mathbf{-202.0614}}{\mathbf{-0.09845873}} = \mathbf{2052}\text{H}$$

$$\boldsymbol{R_C^N} = \frac{\Delta_C}{\Delta} = \frac{\mathbf{-202.0614}}{\mathbf{-0.09845873}} = \mathbf{2052}\text{H}$$

Clamping force $\boldsymbol{Q}$ is equal to the sum of the horizontal components of the normal reaction of the support at point $\boldsymbol{B}$ and the friction force:

$$\boldsymbol{Q} = \frac{\mathbf{2052} \cdot (\mathbf{1} - \mathbf{0.15})}{\sqrt{\mathbf{2}}} = \mathbf{1234}\text{H}$$

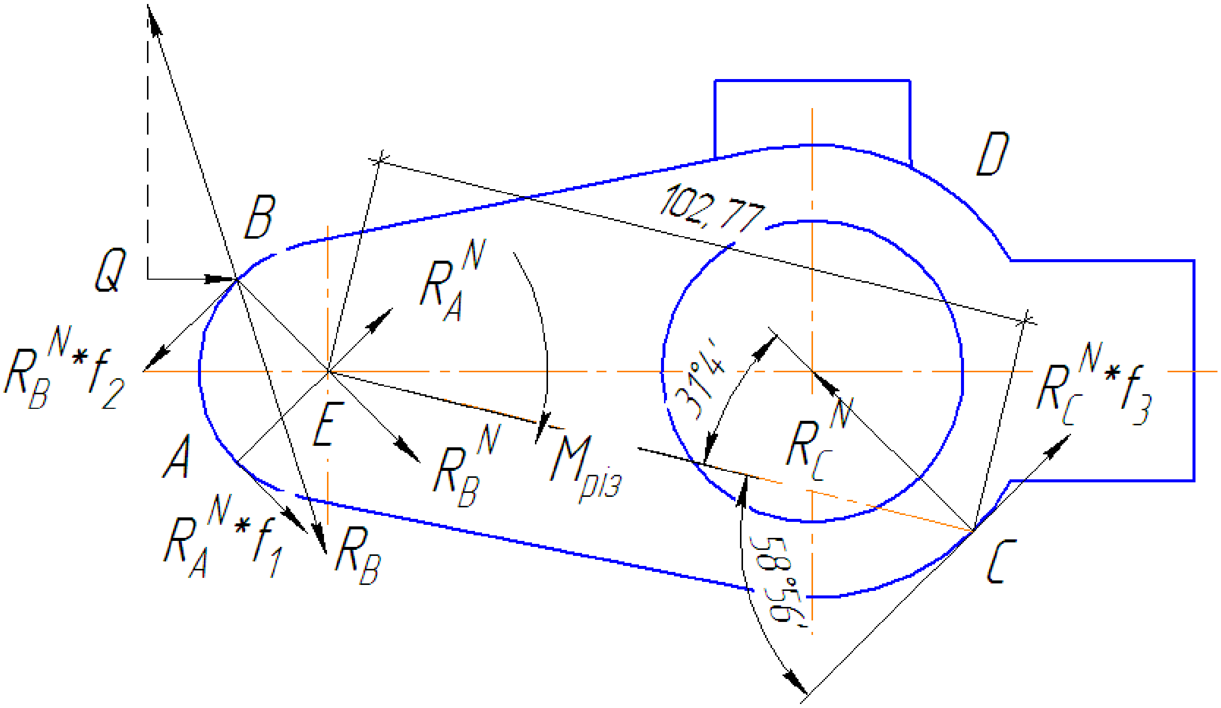


Figure 3.3 Force diagram when drilling a hole Ø25H9

3.1. And, finally, we will calculate the required clamping force $\boldsymbol{Q}$ when milling the surface $\boldsymbol{A}$. In this case, the most unfavorable conditions occur in two cases and the first is when the cutter comes into contact with the workpiece from the side of the clamping mechanism (Fig. 3.4). In this case, we can neglect the action of the axial component of $\boldsymbol{P_X}$the cutting force (the plunger mechanism develops much greater forces and reliably counteracts this component) and consider *the system of forces acting in the plane* . This allows us to significantly simplify the system of equations by solving a system of three equations instead of a system of six equations, which would be a difficult task even with the use of Cramer's method.

Feed force$\boldsymbol{P_h} = \mathbf{0.3} \div \mathbf{0.4}\boldsymbol{P_Z}$ in conditions of symmetrical face milling ***[1, vol. 2, p. 292]*** . We accept $\boldsymbol{P_h} = \mathbf{0.4}\boldsymbol{P_Z} = \mathbf{302.8}$H. Vertical component of cutting force in symmetrical face milling $\boldsymbol{P_v} = \mathbf{0.95}\boldsymbol{P_Z} = \mathbf{719.15}$H. Assuming that at points $\boldsymbol{B}$ and $\boldsymbol{C}$ of contact of the workpiece with the prismatic surfaces of the directional clamp and the fixed support, the reactions of the supports are equal to zero and taking into account that the workpiece will try to "turn" around point $\boldsymbol{D}$, we will compose the equation of moments relative to point $\boldsymbol{D}$:

$$\sum \boldsymbol{M_D} = \mathbf{0} \Leftrightarrow$$

$$\Leftrightarrow \frac{\boldsymbol{R_A^N}}{\sqrt{\mathbf{2}}}[\mathbf{0.1139} \cdot (\mathbf{1} + \boldsymbol{f_1}) + \mathbf{0.0106} \cdot (\mathbf{1} - \boldsymbol{f_1})] + \boldsymbol{K} \cdot (\mathbf{0.02475} \cdot \boldsymbol{P_h} - \mathbf{0.11975} \cdot \boldsymbol{P_v}) = \mathbf{0}$$

$$\boldsymbol{R_A^N} = -\sqrt{\mathbf{2}} \cdot \frac{\boldsymbol{K} \cdot (\mathbf{0.02475} \cdot \boldsymbol{P_h} - \mathbf{0.11975} \cdot \boldsymbol{P_v})}{\mathbf{0.1139} \cdot (\mathbf{1} + \boldsymbol{f_1}) + \mathbf{0.0106} \cdot (\mathbf{1} - \boldsymbol{f_1})}$$

$$\boldsymbol{R_A^N} = -\sqrt{\mathbf{2}} \cdot \frac{\mathbf{3.978} \cdot (\mathbf{0.02475} \cdot \mathbf{302.8} - \mathbf{0.11975} \cdot \mathbf{719.15})}{\mathbf{0.1139} \cdot (\mathbf{1} + \mathbf{0.15}) + \mathbf{0.0106} \cdot (\mathbf{1} - \mathbf{0.15})} = \mathbf{3159.5}\text{H}$$

And again, the force $\boldsymbol{Q}$ is equal to the sum of the horizontal components of the normal reaction of the support at point $\boldsymbol{A}$ and the friction force:

$$\boldsymbol{Q} = \frac{\mathbf{3159.5} \cdot (\mathbf{1} - \mathbf{0.15})}{\sqrt{\mathbf{2}}} = \mathbf{1898.988} \approx \mathbf{1900}\text{H}$$

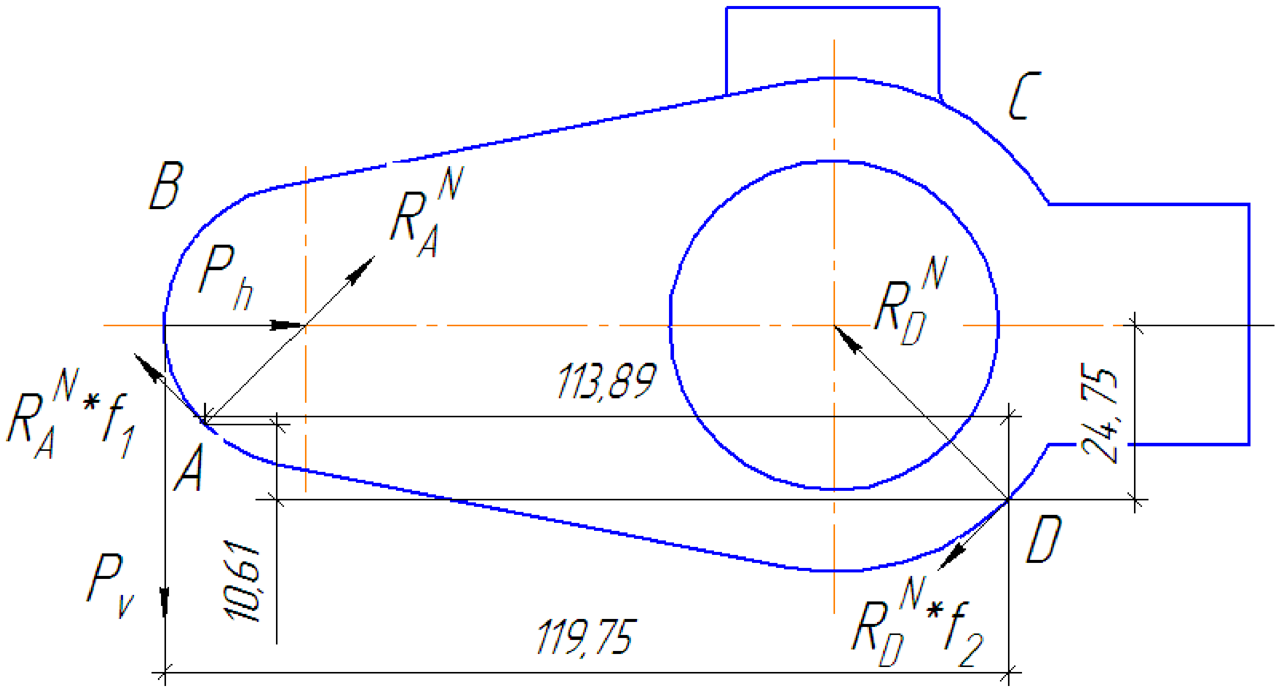


Figure 3.4 Force diagram when milling surface A (at the entrance of the cutter)

3.2. The second case of unfavorable conditions during face milling of surface ***A*** occurs when the cutter leaves the workpiece. The moment relative to point ***D*** (Fig. 3.4) is created due to a much smaller shoulder and will be approximately an order of magnitude smaller than at the beginning of milling. Therefore, the action of the component$\boldsymbol{P_v}$ this time can be neglected: it will have almost no effect on the value of the clamping force ***Q.*** So again, for simplification, let us consider a system of forces *acting in the plane* , but this time plane-parallel to the plane of separation of the flasks. ***F*** (Fig. 3.5).

Under the action of the axial cutting force $\boldsymbol{P_X = 0.55P_Z = 0.55 \cdot 757 = 416.5}$Hand the feed force, $\boldsymbol{P_v = 719.15}$Hthe workpiece will try to rotate around point ***D.*** contact with the plunger (we will consider this point as a fixed point of support, due to the large value of the force of the plunger support in relation to the rest of the forces acting in the problem). Let us compose the equilibrium equation based on the condition that at the point ***E*** of contact of the moving prism with the workpiece the reaction is already zero:

$$\boldsymbol{\sum M_D = 0 \Leftrightarrow (0.017 \cdot P_v + 0.119 \cdot P_X) \cdot K =}$$

$$\boldsymbol{= (Q + K \cdot P_v) \cdot ((f = 0.15) \cdot 0.0845 - 0.018) + Q \cdot (0.088 + (0.15 = f) \cdot 0.0292)}$$

$$Q = K \cdot \frac{(0.017 - 0.15 \cdot 0.0845 + 0.018) \cdot P_v + 0.119 \cdot P_X}{0.088 + 0.15 \cdot 0.0292 + 0.15 \cdot 0.0845 - 0.018}$$

$$Q = 3.978 \cdot \frac{(0.035 - 0.15 \cdot 0.0845) \cdot 719.15 + 0.119 \cdot 416.5}{0.07 + 0.15 \cdot 0.1137} \approx 3000\text{H}$$

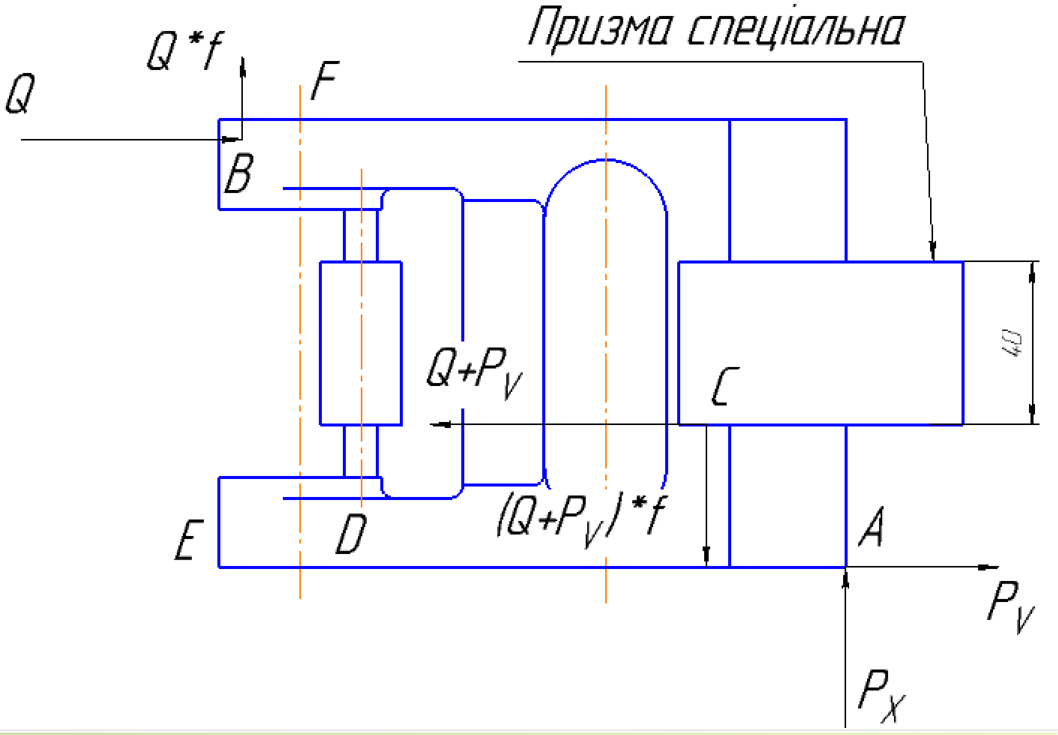


Figure 3.5 Force diagram during milling A (at the exit of the cutter)

So, we found that the minimum clamping force required for the successful completion of the entire operation **005 is Q** is equal to **3000 N.** Taking with a margin, we will take the value Q = *4000 N* for further calculations .

It is necessary to calculate the force ***W*** that will be applied to the wedge mechanism, and the force ***P*** , which the machine operator must apply when tightening the screw mechanism (nut).

So, for a wedge mechanism, as is known *[10]* :

$$W = Q \cdot (\tan(\alpha + \varphi) + \tan \varphi_1)$$

where $f_1 = \tan \varphi_1$ and $\tan \varphi = f$ are the friction coefficients, $\alpha = 90° - (30° \mp 12') = 60° \mp 12'$ is the wedge angle. We assume $f_1 = f = 0.15$, then $\varphi = \varphi_1 = 8.531°$, and:

$$W = 4000 \cdot (\tan(68.531°) + 0.15) = 10771\text{H}$$

As is known, the force that the worker must apply to the wrench handle while tightening the screw mechanism to obtain the clamping force ***W*** is equal to:

$$\boldsymbol{P} = \frac{\boldsymbol{W} \cdot \boldsymbol{r}_{\text{СЕР}} \cdot \mathbf{tan}(\boldsymbol{\varphi}_{\text{ПР}} + \boldsymbol{\psi}) + \boldsymbol{M}_{\text{ТЕР}}}{\boldsymbol{L}}\text{Н}$$

where the friction moment on the nut blank with a hole diameter ***d* = *0.01m*** and the diameter of the surface on the end of the nut $\boldsymbol{D} = \mathbf{14.6 \div 16}$мм (***D* =*0.016m*** – turnkey size for this nut) is equal to:

$$\boldsymbol{M}_{\text{ТЕР}} = \frac{\mathbf{1}}{\mathbf{3}} \cdot \boldsymbol{W} \cdot \boldsymbol{f}\frac{\boldsymbol{D}^{\mathbf{3}} - \boldsymbol{d}^{\mathbf{3}}}{\boldsymbol{D}^{\mathbf{2}} - \boldsymbol{d}^{\mathbf{2}}} = \frac{\mathbf{1}}{\mathbf{3}} \cdot \mathbf{10771} \cdot \mathbf{0.15}\frac{\mathbf{0.016^3 - 0.01^3}}{\mathbf{0.016^2 - 0.01^2}} = \mathbf{10.7}\text{Н} \cdot \text{м}$$

The friction angle is given, taking into account the triangular profile of the thread: $\boldsymbol{\varphi}_{\text{ПР}} = \mathbf{3 \div 5}°$. We accept

$$\boldsymbol{\varphi}_{\text{ПР}} = \mathbf{3}°.$$

lead angle with pitch $\boldsymbol{P}_{\text{РІЗІ}}$and outer diameter $\boldsymbol{D}_{\text{РІЗІ}}$:

$$\boldsymbol{\psi} = \boldsymbol{arctan}\left(\frac{\boldsymbol{P}_{\text{РІЗІ}}}{\boldsymbol{\pi} \cdot \boldsymbol{D}_{\text{РІЗІ}}}\right) = \boldsymbol{arctan}\left(\frac{\mathbf{0.0015}}{\boldsymbol{\pi} \cdot \mathbf{0.01}}\right) = \mathbf{2.7336}°$$

$\boldsymbol{r}_{\text{СЕР}} = \mathbf{0.004513}$м– average thread diameter ***M10*** . $\boldsymbol{L} = \mathbf{0.3}$м– length of wrench handle. So:

$$\boldsymbol{P} = \frac{\mathbf{10771 \cdot 0.004513 \cdot tan(5.7336°) + 10.7}}{\mathbf{0.3}} = \mathbf{52}\text{Н}$$

According to ***[10],*** the hand effort of a machine operator when working with machine tools that use human strength should not exceed ***150N*** . Since the calculated value is ***52N < 150N*** , the calculation is quite satisfactory and is accepted for use.

3.2. Design of the device for operation 010

Description and principle of operation of the device

According to the developed technological process, the workpiece is supported by the machined surface ***A*** on three support points, and two fixed fingers are used as setting elements. Structurally, basing occurs with one cylindrical finger (***Ø50H7***) and one rhombic (***Ø20H9***). Thus, the workpiece loses all six degrees of freedom during basing. Such a basing scheme has many advantages and is widely used in practice. During machining, free access of the tool to all machined surfaces will be ensured. Only when machining surface ***D*** are there difficulties with access by end mills, in connection with which an end mill will be used, although its use (milling diameter ***Ø100mm***) is somewhat "excessive".

The workpiece is fixed on the universal-assembled machine tool device (***USP-12***) with a screw mechanism using a washer from the side of the plane ***K*** in such a way as to press the surface ***A*** to the plate ***7081-2052 GOST 15186-70*** . For this, a slotted bolt ***7002-2083 GOST 15379-70*** , a hexagonal nut ***M12 GOST 5931-70*** and a quick-change washer ***7019-0477 GOST 4087-69 are used*** . The slot in the washer will perform a dual role: firstly, it will accelerate the unfastening-fastening of the workpiece and secondly, it will allow the disk cutter to pass through the slot without damaging the device (washer).

The workpiece base scheme excludes the possibility of its turning over. Therefore, the clamping force ***Q*** should only counteract the workpiece detachment from the surface ***of the USP-12*** . The greatest concerns regarding the cutting forces that will act during operation ***010*** are caused by milling with end mills made of high-speed steel, when the greatest cutting forces arise. Namely, milling the surface ***O*** , when the cutting forces are directed exactly upwards, tearing the workpiece from the support, as well as milling the surfaces ***Zh / Z*** , when the cutting force (previously calculated) acts $\boldsymbol{P_Z = 1512}$H. Let us draw up the equation of equilibrium of the force projections onto the vertical, based on the condition that the workpiece is already on the verge of detachment from the USP, that is, when there is no reaction from the plate side.

Power calculation of the device

Let us calculate the cutting force acting during milling of surface ***O*** with an end mill made of high-speed steel (Fig. 3.6):

$$\boldsymbol{P_Z = 10\frac{C_p h^{X_p} {S_Z}^{Y_p} B^{U_p} z}{D^{Q_p} n^{\omega_p}} K_p = 10\frac{68.2 \cdot 1.5^{0.86} \cdot 0.048^{0.72} \cdot 40^{1.0} \cdot 6}{25^{0.86} \cdot 368^{0}} \left({}^{490}/_{750}\right)^{0.3} = 1440}\text{H}$$

As is known, the feed force during side milling with cylindrical cutters (including end cutters, when the end teeth do not participate in the processing) is the vertical component of the cutting force $\boldsymbol{P_v = (0.7 \div 0.9)P_Z}$. We accept $\boldsymbol{P_v = 0.9P_Z = 1296}$H.

In turn, for counter milling with end mills (***F/C***) the ratio of the feed cutting force to the radial component of the cutting force ***[1]*** : $\boldsymbol{P_h = (1.1 \div 1.2)P_Z = 1.2 \cdot 1512 = 1814.4}$H(Fig. 3.7). Therefore, we will calculate for the value of the force $\boldsymbol{P = 1814.4}$H.

Let's calculate the reserve ratio. This time $\boldsymbol{K_1 = 1.0}$, since we have processing on finishing bases.

Therefore $\boldsymbol{K = K_0 \cdot K_1 \cdot K_2 \cdot K_3 \cdot K_4 \cdot K_5 \cdot K_6 = 1.5 \cdot 1.0 \cdot 1.9 \cdot 1.0 \cdot 1.3 \cdot 1.0 \cdot 1.0 = 3.705 > 2.5}$, the calculated coefficient fully satisfies this requirement.

Then the equilibrium equation has the form:

$$\boldsymbol{\sum Y = 0 \Leftrightarrow Q = K \cdot P_h = 3.705 \cdot 1814.4 = 6722.5}\text{H}$$

The force that the worker must apply to the wrench handle while tightening the screw mechanism to obtain the clamping force Q ***is*** equal to:

$$\boldsymbol{P} = \frac{\boldsymbol{Q} \cdot \boldsymbol{r}_{\text{СЕР}} \cdot \mathbf{tan}(\boldsymbol{\varphi}_{\text{ПР}} + \boldsymbol{\psi}) + \boldsymbol{M}_{\text{ТЕР}}}{\boldsymbol{L}} \text{Н}$$

Where is the friction moment on the nut blank with a hole diameter ***d = 12mm*** and the diameter of the surface on the end of the nut $\boldsymbol{D} = \mathbf{16.6 \div 18}$мм (***D =0.018m*** – turnkey size for this nut) is equal to:

$$\boldsymbol{M}_{\text{ТЕР}} = \frac{\mathbf{1}}{\mathbf{3}} \cdot \boldsymbol{Q} \cdot \boldsymbol{f} \frac{\boldsymbol{D}^3 - \boldsymbol{d}^3}{\boldsymbol{D}^2 - \boldsymbol{d}^2} = \frac{\mathbf{1}}{\mathbf{3}} \cdot \mathbf{6722.5} \cdot \mathbf{0.15} \frac{\mathbf{0.018^3 - 0.012^3}}{\mathbf{0.018^2 - 0.012^2}} = \mathbf{7.665}\text{Н} \cdot \text{м}$$

The friction angle is given, taking into account the triangular profile of the thread: $\boldsymbol{\varphi}_{\text{ПР}} = \mathbf{3 \div 5°}$. We accept

$$\boldsymbol{\varphi}_{\text{ПР}} = \mathbf{5°}.$$

lead angle with pitch $\boldsymbol{P}_{\text{РІЗІ}}$and outer diameter $\boldsymbol{D}_{\text{РІЗІ}}$:

$$\boldsymbol{\psi} = \boldsymbol{arctan}\left(\frac{\boldsymbol{P}_{\text{РІЗІ}}}{\boldsymbol{\pi} \cdot \boldsymbol{D}_{\text{РІЗІ}}}\right) = \boldsymbol{arctan}\left(\frac{\mathbf{0.00175}}{\boldsymbol{\pi} \cdot \mathbf{0.012}}\right) = \mathbf{2.657773°}$$

$\boldsymbol{r}_{\text{СЕР}} = \mathbf{0.0054315}$м– average thread diameter ***M12*** . $\boldsymbol{L} = \mathbf{0.3}$м– length of wrench handle. So:

$$\boldsymbol{P} = \frac{\mathbf{6722.5 \cdot 0.0054315 \cdot tan(7.6577773°) + 7.665}}{\mathbf{0.3}} = \mathbf{42}\text{Н}$$

Since the calculated value is ***42N < 150N*** , the calculation is quite satisfactory to us and is accepted for work.

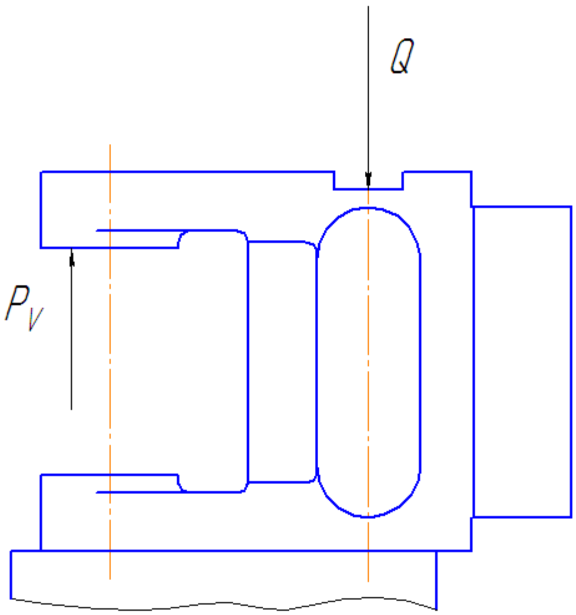


Figure 3.6 Force diagram when milling surface O

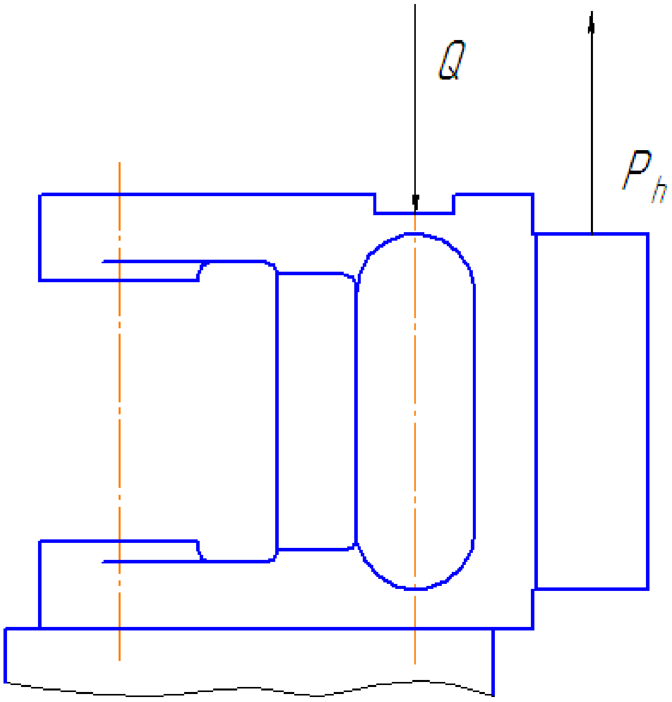


Figure 3.7 Force diagram when milling metal surfaces

4. Economic section

Initial data:

Operation 005 : Equipment – EC-400 , Price = 940,000 UAH .

N UST =14.9 kW , S=12 m 2 , t SHK =19.8 min .

Operation 010 : Equipment – EC-400 , C=940000 UAH .

N UST =14.9 kW , S=12 m 2 , t SHK =12.7 min .

4.1. Determining the required amount of technological equipment

We will conduct economic calculations using the methodology outlined in [3, pp . 40-43].

In conditions of mass production, the estimated number of machines n CPI for each type is determined by the formula:

$$n_{cpi} = \frac{A_{рік} \cdot t_{шт.к.і}}{60 \cdot F_{д} \cdot k_{вн}},$$

where A YEAR — annual program of parts production: 2000 pcs. ; t PIECES I — artificially calculated time of processing parts on the i - th type of equipment, hours; F D – actual annual fund of equipment operating time, hours; k VN — average coefficient of compliance with standards (taken from the range 1.0...1.2).

The actual annual operating time of a unit of equipment is determined by the formula:

F D = F REG · (1 - /100)

where F РЕЖ - the operating time of a unit of equipment per year, hours; - the percentage of equipment downtime in planned and preventive maintenance in relation to the operating time.

Regime fund F DIRECT

F РЕЖ = n ЗМ · (t CM · N ДН.Р – t P · N DAY. Z)

where n ЗМ = 2 – number of work shifts; t CM = 8 hours – duration of working time; t P = 1 hour – number of non-working hours on pre-holiday days; N DN.R = 254 – number of working days per year; N DN. Z = 4 – number of pre-holiday days.

Substituting into the formula

F MODE = 2 · (8 · 254 - 1 · 4) = 4056 hours.

We substitute the obtained value into the formula

F D = 4056 (1 - /100)

we assume 5% , then:

F D = 4056 · (1-0.05) = 3853 hours.

We determine the estimated number of machines:

$$\boldsymbol{n_1 = \frac{2000 \cdot 21.3}{60 \cdot 3853 \cdot 1.1} = 0.167}$$

We accept 1 .

$$\boldsymbol{n_2 = \frac{2000 \cdot 12.7}{60 \cdot 3853 \cdot 1.1} = 0.1}$$

We accept 1 .

Average load factor of equipment for the production of the "Clamp" part :

$$\boldsymbol{k_3 = \frac{\sum n_{cpi}}{n} = 0.1335}$$

Due to the fact that the acquired average value of the equipment load factor is less than k ZSR , typical for serial production, for rational and effective use of the equipment, the machines are additionally utilized by processing other parts in order to achieve a normalized coefficient of 0.8 .

4.2. Hourly current costs

Hourly reduced costs are calculated using the formula:

where S Z — accrual for the salary of service personnel; E N – normative efficiency coefficient of capital investments (for mechanical engineering E N =0.15); C GZ – hourly costs for operating the workplace; K V and K C – specific hourly capital investments in the machine tool and building (workshop), respectively; C EL – electricity costs.

The accrual for the wages of workers servicing the equipment is determined as follows:

S Z = (C OSN + C D) k H

where C OCH - basic salary; C Д - additional salary; k H - coefficient that takes into account accruals for salary:

k H = k FS · k OSS · k FZ · k PF ,

where k FS is the coefficient that takes into account deductions to the accident insurance fund (taken equal to 1.0255); k OSS - coefficient that takes into account deductions to social insurance bodies (taken equal to 1.29); k FZ - coefficient that takes into account contributions to the employment fund (taken equal to 1.016); kPF - coefficient that takes into account contributions to the pension fund (taken equal to 1.323).

Then

k H = 1.0255 1.29 1.016 1.323 = 1.778

The basic salary is determined by the formula:

$$\boldsymbol{C}_{\text{осн}} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{m}} \boldsymbol{C}_{\boldsymbol{Ti}} \cdot \boldsymbol{\eta}_{\text{П}} \cdot \boldsymbol{\eta}_{\text{Д}} \cdot \boldsymbol{\eta}_{\text{З}}$$

where CTi - hourly tariff rate of the i -th worker, servicing equipment, UAH (3rd category – 35 UAH , 4th category – 45 UAH , 5th category – 55 UAH); p - coefficient that takes into account additional payments for professional skills, foreman, etc. (selected from the range 1.04...1.20); d - coefficient that takes into account additional wages (selected from the range 1.06...1.08); with — coefficient that takes into account social insurance deductions (c = 1.52).

Additional wages are determined by the formula:

C D = 0.2 · C OSN = 35.46 hryvnias/hour

C C = (177.3+35.46) · 1.778=378.3 UAH/hour.

Hourly costs for operating the workplace :

$$\boldsymbol{C}_{\text{Г.З.}} = \boldsymbol{C}_{\text{Г.З.}}^{\text{Б.П.}} \cdot \boldsymbol{k_M}$$

S BP GZ – practical hourly costs at the basic workplace, S BP GZ = 60 UAH. – a coefficient showing how many times the costs associated with a given machine exceed the costs of working with the base machine, .

$$\boldsymbol{C}_{\text{Г.З.}} = \boldsymbol{60 \cdot 1.1 = 66 uah/h}$$

Since the machine is not fully loaded, the parameter C GZ it is necessary to adjust and use the values of S K GZ for calculations :

$$\boldsymbol{C}_{\text{Г.З.}}^{\text{К}} = \boldsymbol{C}_{\text{Г.З.}} \frac{\boldsymbol{\varphi}}{\boldsymbol{1.14}} = \boldsymbol{C}_{\text{Г.З.}} \frac{\boldsymbol{1} + \frac{\boldsymbol{\alpha(1 - k_{\text{З}})}}{\boldsymbol{k_{\text{З}}}}}{\boldsymbol{1.14}} \boldsymbol{uah/h}$$

Where is the correction factor:

$$\boldsymbol{\varphi = 1 + \frac{\alpha(1 - \eta_{\text{З}})}{\eta_{\text{З}}}}$$

– the share of fixed costs in the cost of hourly labor at the workplace, – the calculated machine load factor. Finally:

$$\boldsymbol{C}^{\text{К}}_{\text{Г.З.}} = \mathbf{66}\frac{\mathbf{1} + \dfrac{\mathbf{0.29(1 - 0.1335)}}{\mathbf{0.1335}}}{\mathbf{1.14}} = \mathbf{166.81}\, \boldsymbol{uah/h}$$

Electricity costs :

$$\boldsymbol{C}_{\text{Е}} = \boldsymbol{N}_{\text{ДВ}} \cdot \text{Ц}_{\text{Е}} \cdot \boldsymbol{R}_{\text{В}} \cdot \boldsymbol{R}_{\text{М}}$$

where N DV - power consumed by the machine, kW; Ts E - average cost of 1 kW of electricity, which takes into account both the tariff for 1 kW of electricity and 1 kW of installed capacity, Ts E = 1.5 UAH / kW h ; R B - coefficient that takes into account the use of equipment during the working day (taken equal to 0.85); R M - coefficient that takes into account the use of capacity during the working day (taken equal to 0.7) ; m - number of operations required to manufacture the product.

$$\boldsymbol{C}_{\text{Е}} = \mathbf{14.9 \cdot 1.5 \cdot 0.85 \cdot 0.7 = 13.3}\, \boldsymbol{uah/h}$$

Capital costs for the machine :

$$\boldsymbol{K}_{\text{В}} = \frac{\text{Ц}_{\text{ОБ.Т}}}{\boldsymbol{n} \cdot \boldsymbol{F}_{\text{Д}} \cdot \boldsymbol{k}_{\text{з}}} = \frac{\mathbf{940000}}{\mathbf{4 \cdot 3853 \cdot 0.1335}} = \mathbf{456.865}\, \boldsymbol{uah/h}$$

where C OB.T I - cost of a unit of technological equipment, UAH/unit ; k C - equipment load factor, n = 4 - the service life of the machine tool accepted for calculations.

Capital costs for the building :

$$\boldsymbol{K}_{\text{Ц}} = \frac{\boldsymbol{S} \cdot \text{Ц}_{\text{ПЛ}} \cdot \boldsymbol{\eta}_{\text{Д}}}{\boldsymbol{F}_{\text{Д}} \cdot \boldsymbol{k}_{\text{з}}}$$

Where S is the total area occupied by the equipment (in plan). S = (1.07...1.10) · (S VN.PR + S VN.DOP), 1.07...1.10 - coefficient that takes into account the internal area when measuring externally; S VN.PR – internal production area, m 2 . S VN.PR = (12+3.5+2.5) · 3.5 = 63 m 2 . S VN.DOP – internal area of auxiliary premises, m 2 . S VN.DOP = 31.5 · 0.25 = 16 m 2 .

Therefore:

S = 1.1 · (63 + 16) = 87 m 2

C PL – specific cost of production area 1000-1300 UAH/m 2 ; – coefficient that takes into account additional area for aisles, etc. .

$$\boldsymbol{K}_{\text{Ц}} = \frac{\mathbf{87 \cdot 1120 \cdot 1.3}}{\mathbf{3853 \cdot 0.1335}} = \mathbf{246.27}\, \boldsymbol{uah/h}$$

Finally :

$$\boldsymbol{C}_{\text{П.З.}} = \mathbf{378.3 + 166.81 + 13.3 + 0.15(456.865 + 246.27) = 663.88}\ \boldsymbol{uah/h}$$

Technological cost of the operation :

$$\boldsymbol{C}_{\text{О}\,\boldsymbol{i}} = \frac{\boldsymbol{C}_{\text{П.З.}} \cdot \boldsymbol{t}_{\text{шт.к.}\boldsymbol{i}}}{\mathbf{60} \cdot \boldsymbol{k}_{\text{В}}}$$

Where – the coefficient of compliance with the norm.

$$\boldsymbol{C}_{\text{О}\,\mathbf{1}} = \frac{\mathbf{663.88 \cdot 19.8}}{\mathbf{60 \cdot 1.3}} = \mathbf{168.52}\ \boldsymbol{uah}$$

$$\boldsymbol{C}_{\text{О}\,\mathbf{2}} = \frac{\mathbf{663.88 \cdot 12.7}}{\mathbf{60 \cdot 1.3}} = \mathbf{108.1}\ \boldsymbol{uah}$$

4.3. Calculation of the cost of the workpiece

The mass of the part is 2.75 kg (Fig. 4.1), the mass of the blank is 3.87 kg (Fig. 4.2). We calculate the cost of casting according to the formula [14] :

C ZAG = (C/1000) ·G·K T · K C ·K O ·K M ·K P – (G - g) · (C VIDH /1000) , UAH=

=7.2·3.87·1.21·1·1·1·1 – (3.87 – 2.75) ·0.452=33.2 hryvnias .

Here C = 7200 UAH – basic cost of 1 ton of billets, UAH;

K T =1.21, K C =1, K O =1, K M =1, K P =1 – coefficients that depend on the accuracy class, complexity group, mass, material grade and production volume of blanks.

G – mass of the workpiece, kg ;

g – mass of the finished part, kg ;

C WASTE = 452 UAH – cost of 1 ton of waste, UAH .

4.4. Cost of manufacturing the part "Clamp"

The final cost of manufacturing the " Clamp " part consists of the cost of manufacturing the workpiece and the cost of its machining:

$$\boldsymbol{C} = \boldsymbol{C}_{\text{ЗАГ}} + \boldsymbol{C}_{\boldsymbol{O}\,\mathbf{1}} + \boldsymbol{C}_{\boldsymbol{O}\,\mathbf{2}} = \mathbf{33.2 + 168.52 + 108.1 = 309.82}\ \boldsymbol{uah}$$

The calculation is simplified and does not take into account many factors such as, for example, the cost of the tool, the cost of USP 12 kits and the assembly of machine tools from them, the manufacture of special parts and assemblies of machine tools, etc., however, we will consider the volume of calculations performed sufficient to complete the task.

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3. James Madison. CNC Machining Handbook: Basic Theory, Production Data, and Machining Procedures, 2006

Appendix. G-Code for 005 operation

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N300Y167.625
N310X0.000
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N420Y279.375
N430X0.000
N440Y298.000
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