APPLICATION A CAM SYSTEM AS ENGINEERING METHOD OF INTENSITY CALCULATION

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This article discusses the main aspects related to the software of the automated system «Lineika». The main function of the CAM «Lineika» is to assess the predictive complexity and cost of manufacturing parts and products of tool production. The system provides an automated calculation of the above technical and economic indicators for the following groups of class 28, allocated by regulatory documents: cutting tool; measuring tool; appliances, dies, moulds, production accessories. Approbation of the created automated system in real production conditions showed the high efficiency of the proposed engineering method of rationing in the calculation of the projected intensity of the production of cutting, measuring tools, as well as forming parts of tooling. Its introduction into the pilot production of the development of new products will significantly reduce the time required for the development of new device designs for manufacturability, which in general will reduce the final cost of production.

KEYWORDS

CAM; CAPP; cost of manufacturing; labour complexity; labour intensity

1 INTRODUCTION

The automation of technical production preparation represents a very important step in the development of automated production systems. The basic representatives are CAD (Computer-Aided Design) [Kyratsis 2020], CAM (Computer Aided Manufacturing) [Peterka 2008a and 2014, Pokorny 2012, Vopat 2013] CAPP (Computer Aided Process Planning) [Kuric 2006, Debnarova 2014, Nguyen 2020] CAA (Computer Aided Assembly) [Peterka 2008b, Vaclav 2017a], and then systems controlling production machines, robots, lines, equipment, and systems such as NC (Numerical Control) and CNC (Computer Numerical Control). Researchers, developers, and engineers are designing various applications and their interconnections to increase the degree of automation. Different standardized codes such as G-code for ISO programming [Debnarova 2014, Dodok 2017] and others, protocols e.g. STEP-NC (Standard for the Exchange of Product Model Data - Numerical Control) [Dharmawardhana 2021, Garrido 2021] but also custom applications are used.

Technological production preparation (TgPP) is a totality of technical-organizational activities and measures aimed at processing production documentation and bases for material equipment of the production process [Dyadyura 2021]. The analyses of the workload composition show that 70% to 80% of the total workload is attributed to the preparation of production documentation. After the development and design stage, in which the design of the component was implemented, the design of the production technology follows. The design of the production method, which is written into the technological documentation, is realized in the framework of technological production preparation (TgPP). This part of the pre-production stage is one of the most laborious and time-consuming in the preparatory phase of the production process.

The main task of TgPP is mainly:

- processing of design and technological analyses of the component base,
- selection of suitable semi-finished products,
- determining the number and sequence of manufacturing, inspection, and assembly operations,
- selection of suitable machines, tools, jigs, gauges, and aids,
- calculation of basic techno-economic data on material and energy consumption,
- processing, completion, and archiving of production documentation,
- processing and modification of production documentation in the framework of change management,
- determination of cutting conditions and time consumption standards,
- classification and processing of handling and transport operations,
- processing programs for NC machines, robots, and control equipment,
- processing documentation for product assembly [Vaclav 2017b].

In the modern manufacturing industry, the role of computer-aided process planning (CAPP) is becoming increasingly crucial. Through the application of new technologies, experience, and intelligence, CAPP is contributing to the automation of manufacturing processes [Jakubowski 2014, Hlavac 2018]. The interconnection of CAD-CAM-CNC systems is described in [Peterka 2014]. In the article [Nguyen 2020], the integration of a proposed CAPP system that is named as BKCAPP and G-code generation module provides a completed CAD–CAPP–CNC system that does not involve any manual processing in the CAM modules. The BKCAPP system is capable of automatically performing machining feature and operation recognition processes from design features in 3D solid models, incorporating technical requirements such as the surface roughness, geometric dimensions, and tolerance to provide process planning for machining processes, including information on the machine tools, cutting tools, machining conditions, and operation sequencies [Saga 2020a,b]. G-code programs based on macro programming are automatically generated by the G-code generation module based on the basic information for the machining features, such as the contour shape, basic dimensions, and cut-ting information obtained from BKCAPP. The G-code generation module can be applied to standard machining features, such as faces, pockets, bosses, slots, holes, and contours. This novel integration approach produces a practical CAPP method enabling end-users to generate operation consequences and G-code files and to customize specific cutting tools and machine tool data.

The Special Issue [Kyratsis 2020] includes papers that cover a variety of relevant issues and provide an opportunity for researchers to present recent advances in CAD/CAM/CAE technologies.

Many authors present their methods for assessing the complexity of manufacturing engineering products or assembly, assessing the suitability of technology and manufacturing machinery. It is based on the standard [GOST 1980], which establishes a single, impersonal classification system for designating products of the main and auxiliary production and their design documents of all industries in the design, manufacture, operation, and repair.

An automated chronometric system developed for assessing the difficulty of machining operations in manufacturing is reported in [Tyurin 2017]. The system facilitates and improves labour organization and standardization in the machine-tool workshop. The paper of Michalik [Michalik 2011] deals with two CAM software products that are used for the creation of programs for CNC machining. Proceeding of programming itself depends on the kind of CNC machine, geometrical shape and requested accuracy, kind of workpiece material, and also on possibilities of the software. Authors in [Dombrachev 2015] solve the calculation of time standards in manufacturing using the «Lineika» (Note: Lineika (the etymology of the word in Russian) – is a measuring tool for drawing straight lines, equipped with divisions to determine the length of the segment) CAM system is considered. This system may be used to assess the precision of time standards calculated analytically.

The papers of Bozek [Bozek 2014 and 2016] are primarily aimed to address issues with whose functional, organizational, personnel, and material means can be improved and optimize the entire course material flow manufacturing enterprise. In [Martinovic 2021], authors use an index of capability, that describes machine capability for concrete technology. A high index of capability means that there is a properly functioning machine, with a small spreading around the tolerance width of dimensions of parts. The research is focused on machine capability. The results of measuring the accuracy of the tolerated dimension of the inner holes after broaching are used as input values to this statistic.

In [Vaclav 2007], there is described OMA (Objective Method Assembly) method for assembly. OMA is a complementary method to all known methods of DFA (Design for Assembly). OMA describes assembly, according to the theory of systems as a subsystem of the production system, whose aim is to achieve profit in assembly. Design of product is only one factor in the way to achieve the goal. Instead of subjective marking by evaluation of results, OMA offers to use three objective criteria: the sum of assembly paths, the number of assembly actuators, and the so-called grade of intelligence of assembly task.

An important problem in assembly is repeatable precision, mainly in the construction of assembly lines. In the article are shown reasons and security approach of repeatable precision in assembly operations executing [Vaclav 2017c]. In the paper [Lamikiz 2005], the authors present the CAM system whose final objective is to generate reliable CNC programs. In this manner, the CAM becomes the centre of gravity of the machining planning procedure. They use the methodology that has been applied to the machining of two plastic moulds. Time, tolerances, and surface roughness have been measured to check the success of the purposed methodology. In this paper [Karpus 2018], the ways of intensification of machining complex parts on modern metal-cutting equipment were described. The classification of parts was developed based on design and technological features. Based on the developed classification the structural code that allows encoding any design was proposed. The structural code can be used in computer-aided fixture design. Comparative analysis of manufacturing processes by labour content, the number of fixtures and machine tools, number of setups, and production area was performed.

In this paper, a machining part consisting of basic machining features was used to describe the method and verify its implementation. Presented research is focused on assessing the predictive complexity and cost of manufacturing parts and tooling products using a CAM system and a custom software application. The main actions of the technologist and the norm setter when working with the system comprise: determining the overall dimensions of a part or product, establishing a middle class of finish accuracy, selection of the main design, and technological elements. All source data are determined based on a set of drawings, at the same time additional development of operational or route technological process is not required; computing associated with the calculation of the projected values of labour complexity and cost of manufacturing parts or products are performed automatically by the system. The results of forecasting can be used in the future as in the decision to put into the production of the newly manufactured product and to adjust and verify the regulatory framework used in the enterprise. The design system of technological processes «Lineika» was developed at the department "Organization of computer processes and control systems» at the Votkinsk branch of Kalashnikov Izhevsk State Technical University. The system is implemented as a win32-application and is adapted to run under all versions of existing operating systems of the Windows family. Currently, the system is introduced into the production of several machine-building enterprises in Udmurtia and the Ural region, its use has significantly reduced the time spent by specialists of the departments of labour and wages for a preliminary estimate of the complexity and cost of manufacturing products. Next, we consider the engineering methodology of rationing, which is the basis of the mathematical support of the system.

2 MATERIALS AND METHODS

The basis for the calculation of the projected labour intensity of instrumental production is based on standard technological processes and the estimated time standards using statistical materials of machine-building enterprises. The planned labour intensity of the product is considered as a statistically determined function depending on its structural complexity [Slezinger 1955, Yakimovich 1994, Dombrachev 2004, Cacko 2014].

2.1 The calculation of the projected labour intensity

When calculating the projected labour intensity of products using CAM "Lineika" it is proposed to use the following relationships (1), (2), and (3).

For calculation of the index of complexity of the product we use the equation (1):

$$C = \sum_{i=1}^{n} \sum_{j=1}^{l} c_{ij} \qquad (1)$$

where C – index of complexity of the product, defined as the sum of the complexity of its parts; c_i – index of complexity of a single structural element; l – the number of structural elements identified in the part included in the product; n – total number of parts in an assembly to specification, including borrowed and purchased parts.

For calculation of projected labour intensity of products, we proposed equation (2):

$$T^{IZD} = 41.10^{-4} K_{\delta} (l \times B \times H)^{0.3} m^{0.1} n^{0.25} C^{0.4} \qquad (2)$$

where T^{IZD} – projected labour intensity of manufacturing products, normal hours; K_d – product precision factor; L, B, H – length, breadth, and height – overall dimensions of the product, mm; m – the number of newly manufactured parts.

For calculation of projected labour intensity of product, we use equation (3):

$$T_{OTY}^{IZD} = a + bT^{IZD} \tag{3}$$

where T_{OTY}^{IZD} – projected labour intensity of manufacturing the product, taking into account the current working conditions of the enterprise, normal hours; a, b – regression coefficients that allow specifying the value of the projected labour intensity by the current production conditions of the enterprise.
When calculating the projected labour intensity of parts (Figure 1) in the CAM "Lineika" uses the following dependencies:

$$C = \sum_{j=1}^{l} c_j \tag{4}$$

$$T_i^{DET} = 41.10^{-4} K_\delta (l \times B \times H)^{0.3} c_i^{0.4} \tag{5}$$

$$T_{PRi}^{DET} = a + bT_i^{DET} \tag{6}$$

$$T_{OTY}^{IZD} = \sum_{i=1}^{n} T_{OTY_i}^{DET} \tag{7}$$

Precision factor (K_d) depends on the linear size E, measured in [mm], and the tolerance on it (d), measured in [µm]; on the element of the part, performed with the most rigid technological parameters:

$$K_\delta = 2.11 \frac{E^{0.04}}{\delta^{0.12}} \tag{8}$$

If the size and tolerance are expressed in angular values, then they are converted to linear values based on the following approximate dependencies:

$$E = 0.02R\alpha \tag{9}$$

$$\delta = 0.3R\Delta\alpha \tag{10}$$

where E – linear dimension, [mm]; δ – tolerance scope, [µm]; R – the largest radius of the arc or the length of the largest side of the angle, [mm]; a – selected angle, [°]; Da – angle tolerance, [min].

The following is an example of tolerance conversion (Figure 1).

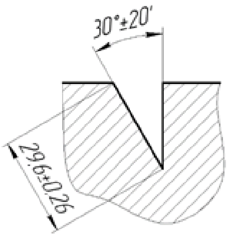


Figure 1. An example of determining E and d by a known angular value

Along with the computing method for determining the coefficient K_d, it is permissible to use an approximate method of estimation based on accuracy classes. Accuracy class in mechanical engineering – used in Russia characteristic of the accuracy of manufacturing products (parts), is now replaced by quality. Table 1 shows accuracy classes, and the corresponding values of the coefficient K_d.

(K_T)	9	8	7	6	5	4	3
(K_d)	1.00	1.09	1.11	1.16	1.21	1.33	1.51

Table 1. Accuracy classes (K_T) and Precision factor (K_d)

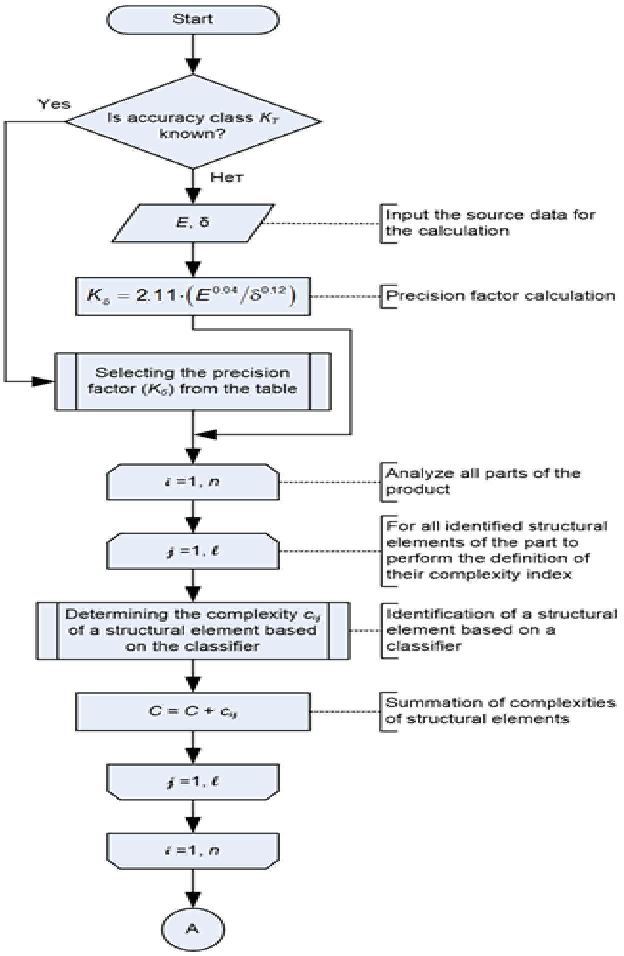
When determining the precision factor, the following should be considered:
- for appliances, E and d values are usually taken at the most accurate installation size;
- for dies – at the most accurate size of the matrix or punch;
- for moulds and injection moulds – at the most accurate working surface size.

The geometric parameters of the devices used in the formulas (1, 2) include the overall dimensions of the tool L, B, H.

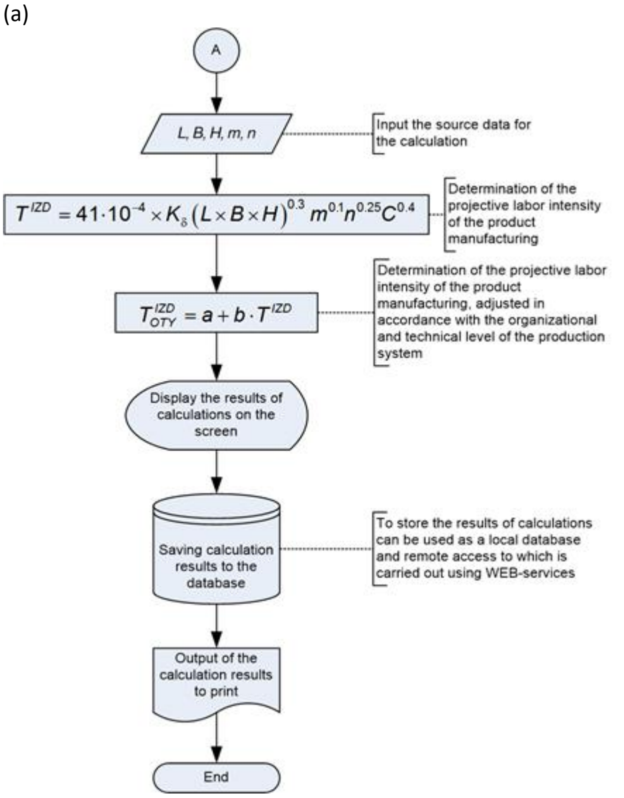
When determining the overall dimensions of the measuring tool, the following features are taken into account:
- the tool with moving parts is considered in the position of their closest approach;
- for a tool, one of the projections of which represents a circle, the square with a side equal to the diameter is taken as the dimensional parameters.

The minimum value of L, B, H is 100 mm. If the value found in the drawings is less than the specified value, the minimum possible value should be used. The main parameter that has the greatest impact on the value of the projected complexity of the manufacture of parts and products, is an indicator of complexity. Indicator of complexity – this is a dimensionless value that characterizes the complexity of the processing of design and technological elements of the part.
In the method under consideration, a relative system for assessing the complexity of design and technological elements is used. This means that some element, the intensity of processing that is taken as the base value, has a complexity equal to one. The complexity of the remaining elements can be considered as an indirect indicator of how many times the intensity of their processing is above the base element.
Flowcharts of computing algorithms that implement the designed calculation method are shown in Figure 2.
In the considered engineering method of rationing, the complexity of the conventional base element is taken as the unit – open, easily accessible for processing, a straight surface parallel to the setting base. The number of conventional basic elements also includes an element that is a cylinder with a length not exceeding triple of its diameter. The complexity of the remaining structural elements is defined as the ratio to the complexity of the base.
All structural elements of products similar in form, shape, or dimensional characteristics are divided into two groups, characterized by the availability of their surfaces for machining.

The first group includes all the external open surfaces, bodies of rotation (cylinders, ends, cones), rounding, and parts of the circle (both convex and concave), which are elements of the external surfaces and have a free exit for processing.
The second group includes all internal or closed planes that do not have a free exit for processing; internal cylindrical, end, and conic surfaces; rounding and parts of a circle, either elements of internal surfaces or not having a free exit for processing.



(a)



(b)

Figure 2. Flowchart of the algorithm of computing provided by the method of calculating the projected labour intensity of products – (a) Section 1, (b) Section 2

As an example, consider the areas of processing (zone) for milling parts. They are usually divided into exposed, half-exposed, hidden, and combined (Figure 3). It is common to refer to the exposed areas that do not impose any restrictions on the movement of the tool along its axis or in a plane perpendicular to it. In half- exposed areas, tool movements are limited both along the axis and in the plane perpendicular to it. In hidden areas, tool movement is limited in all directions

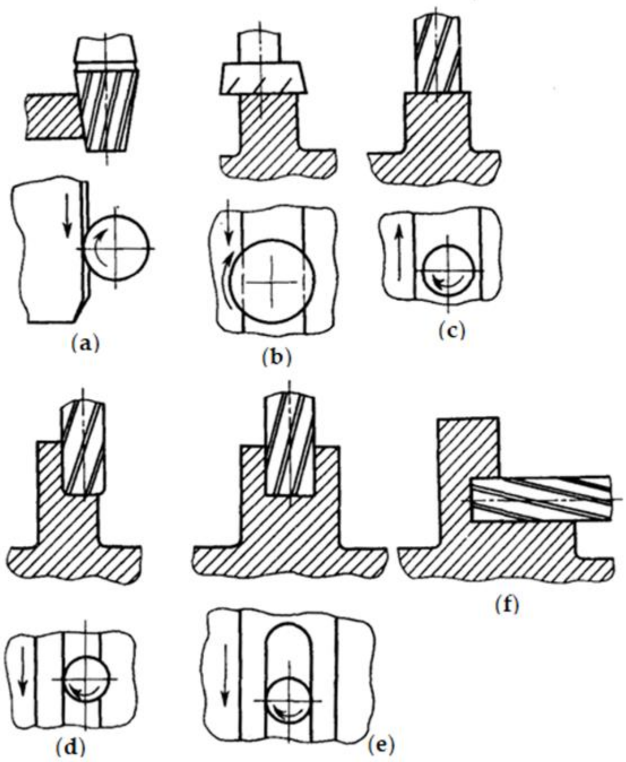


Figure 3. Milling treatment areas: exposed: (a) cylindrical milling cutter; (b) face mill; (c) end mill; (d) half- exposed (end mill); (e) hidden (end mill); (f) combined (end mill)

It is common to refer to the exposed areas that do not impose any restrictions on the movement of the tool along its axis or in a plane perpendicular to it. In half-exposed areas, tool movements are limited both along the axis and in the plane perpendicular to it. In hidden areas, tool movement is limited in all directions. Interventional studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

2.2 Application of intensity calculation

Combined areas are formed as a result of combining several areas of different types, from those described above. With the same geometric parameters, the complexity of the working surfaces of the second group is 1.5 times higher as compared to the first one.

Assessing the complexity of the product as a whole takes into account all existing working and guide surfaces. At the same time, the complexity of the structural elements that are the guide surfaces is taken in 2 times less, compared with similar elements, representing the working surfaces. In Figure 4 are the main elements used in the calculation of the complexity of products and the corresponding values of the complexity index.

To determine the complexity of devices and tooling, it is necessary to follow the rules for determining the value of the complexity index.

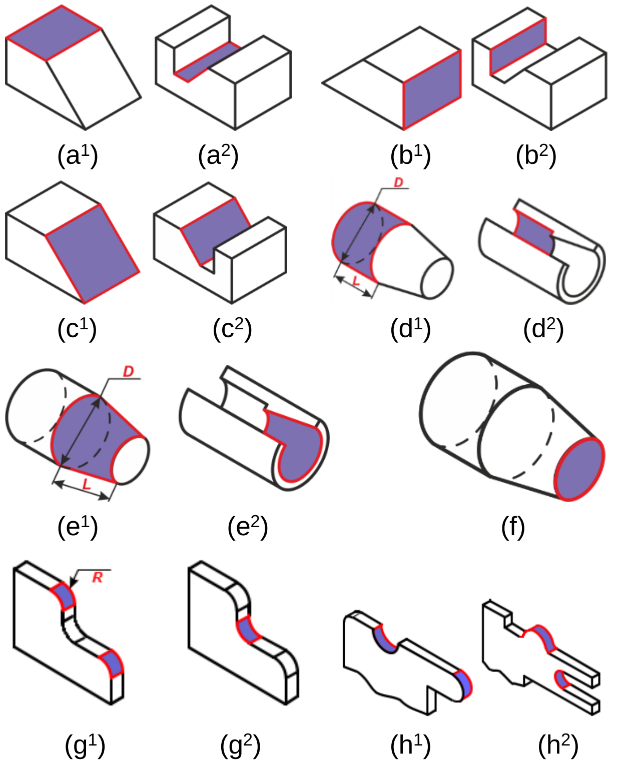


Figure 4. The basic structural elements: (a) Parallel surface (to the setting base); (b) Perpendicular surface (to the setting base); (c) Inclined surface (to the setting base); (d) Smooth cylinder; (e) Smooth cone; (f) End face; (g) Rounding; (h) Part of the circle, ^{1} – the exposed element, ^{2} – the hidden element

Structural element	The exposed element	The hidden element
Parallel surface	1	1.5
Perpendicular surface	2	3
Inclined surface	2	3
Smooth cylinder	$C = \frac{L}{3D}$	$C = \frac{L}{2D}$
Smooth cone	$C = \frac{2L}{3D}$	$C = \frac{L}{D}$
End face	1	-
Rounding	*If R* ≤ *1* mm Then *C = 1*, *If R > 1* mm Then *C = 1*	*If R* ≤ *1* mm Then *C* = *1.5*, *If R > 1* mm Then *C = 3*
Part of circle	3	4.5

Table 2. The complexity of the elements in Figure 5

The working surfaces of tooling include surfaces intended for the installation of the product or cutting tool, as well as installation or setting structural elements for the installation of the tooling. As an example, a turning centre (Figure 5), designed for basing and fixing the workpieces of the "shaft" type, was installed in the driver chuck during their processing on CNC lathes.

The device consists of a housing 1 with a centre 2 installed in its head-on two radial ball bearings 3 and one thrust ball bearing 4. Radial bearings, respectively, perceive radial loads, and thrust–axial. Ball bearings are pressed by a nut 5, in the cavity of which a gland 6 is installed, which protects the ball bearings from contamination and keeps the grease. Nut 5 is fixed by locking screw 7. Ball bearings are lubricated through the threaded hole in the housing, closed with a screw 8.

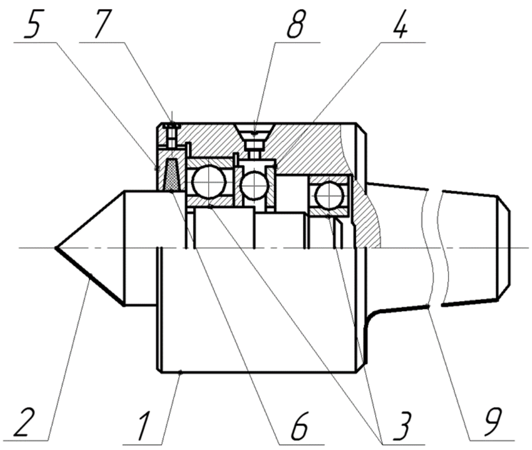


Figure 5. Sketch of a turning centre: 1 – housing; 2 – centre; 3 – radial ball bearings; 4 – thrust ball bearing; 5 –nut; 6 – gland; 7 – locking screw; 8 – screw that covers the hole for grease

When determining the complexity of the considered device, it should be taken into account that centre 2 is in contact with the end of the workpiece, and the shank 9, made in the form of a Morse code, is used to install the device in the chuck.

Therefore, centre 2 should be considered as an exposed work surface cone with complexity equal to $C = 2 \times 1.5 = 3$ complexity units. The shank 9 should be considered as a set of working surfaces, the first of which is perpendicular to the setting base, and the second is a conical surface, and their total complexity is $C = (2 + 2) \times 1.5 = 6$ complexity units.

3 DISCUSSION

In the general case, when determining the index of complexity of tooling, first of all, the following structural elements of its parts are taken into account:

- Surfaces that determine the position of the tooling relative to the equipment, such as the setting and support surfaces of plates or other body parts.
- Surfaces of equipment parts, such as clamps, quick-release washers, fingers, and others, the surfaces of which ensure the connection of the equipment with the product and its fixation.
- Surfaces that determine the position of the working tool relative to the product, for example, the inner surfaces of the jig bushings, the surfaces for installing probes, the working surfaces of probes, and others that have a similar technological purpose.

In all cases, when determining the complexity index, threaded fixing surfaces that are integral during the operation of the tooling, as well as the surfaces of set pins, pins, and corresponding holes, are not taken into account.

In the presence of the equipment in contact with the working surfaces on different parts, the surfaces on each of the parts are taken into account. For example, in a sleeve and a roller, the contact surfaces of which are working, the corresponding surface is taken into account both on the sleeve and on the roller.

Complex devices containing more than ten assembly units are preferable to normalize the assembly, determining the overall dimensions (L, B, H) based on the assembly drawing, the total value of the complexity index based on drawings, and setting based on the specification the number of newly manufactured (m) and the total number of parts (n). For calculations, it is necessary to use the formulas (1, 2, 3) and the flowchart of the order of computing given in Figures 2 and 3.

If the parts of the device include form surfaces, for processing of which complex mechanical processing equipment or electro-erosion processing is supposed to be used, and the labour intensity of manufacturing parts containing such surfaces must be distinguished from the total labour intensity of tooling, then it is allowed to calculate in detail, considering every part as a separate product. For calculations, one should use the formulas (4, 5, 6, 7).

4 CONCLUSION

Considered in this article, the engineering method of standardization of parts and products of tool production became the basis of mathematical software CAM "Lineika", implemented in the form of win-32/64 applications using object-oriented programming methods in the Borland Delphi environment. The proposed automated rationing system, which allows performing:

- rationing of parts and products,
- plan production,
- carry out design stages before performing design and technological processing,

which makes it possible to estimate the cost of production and profitability of production,

with a sufficient degree of reliability. Approbation of the created automated system in re-al production conditions showed high efficiency of the proposed engineering method of rationing:

- in the calculation of the projected intensity of the production of cutting,
- measuring tools,
- as well as forming parts of tooling.

Its introduction into the pilot production of the development of new products will significantly reduce the time required for the development of new device designs for manufacturability, which in general will reduce the final cost of production.

The current trend is to use computer support, mathematical methods, and artificial intelligence methods in a wide range of different areas. We encounter computer systems in the analysis of experimental data [Peterka 2020a,b], artificial neural networks (ANN) [Abbas 2018, Kolesnyk 2022], fuzzy logic, autoregressive integrated moving averages [Borkin 2019], and machine learning methods [Nemeth 2019] are used in engineering, among others. ANNs are proving their applicability as a versatile tool for analysing various not only non-technical [Peterkova 2018] but also engineering processes [Pavlenko 2019] such as: cutting force in grinding [Pavlenko 2020], prediction of milling process parameters [Parmar 2020], surface roughness in turning [Abbas 2018], and milling [Zhou 2020]. Accordingly, in the next research, authors plan to implement artificial intelligence methods and ANN procedures in the CAM system “Lineika”, for standardization of parts and tooling products.

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