UDC 629.3.021 DOI: 10.30977/AT.2219-8342.2023.52.0.02

Computer modeling and software research of car and engine parts

Kalchenko V.[1], Kolohoida A.[1], Pasov H.[1], Sira N.[1], Klymenko V.[2]

[1]Chernihiv Polytechnic National University, Ukraine
[2]Kharkov National Automobile and Highway University, Ukraine

Abstract. Problem. *The development of automotive technology for various purposes and the improvement of existing car models, requires a fast and flexible design process. Spatial models of details and nodes are the starting points for design, and the necessary design documentation is performed on their basis. When manufacturing parts on CNC machines, it is necessary to quickly obtain a control program that will increase the accuracy of the product by ensuring the optimal trajectory of the mutual movement of the part and the tool. Therefore, the creation of a comprehensive methodology for the design of car parts, their basic inspection and obtaining design documentation is an important technical task.* ***Goal.*** *The main goal of the work is to determine the rational sequence and basic principles of computer-aided design, research and manufacturing of car and engine parts, and the development of mathematical spatial models of surfaces in order to optimize control programs for CNC machines.* ***Methodology.*** *The approaches adopted in the work for solving the set goal are based on general design principles. The methods of conducting static and dynamic calculations, as well as spatial mathematical modeling of the processes of manufacturing parts were also used.* ***Results.*** *A comprehensive methodology for designing parts of engines and cars has been developed. The main principles of creating spatial models have been determined in order to achieve their flexibility and simple editing. Methods of automating the development of drawings and design documentation are described. The software options for the primary verification of static strength and frequency analysis are considered. A calculation program has been developed for constructing transient and amplitude-phase-frequency characteristics. The mathematical spatial modeling of typical surfaces of the camshaft is provided with the aim of further research and optimization of the development of a control program for processing on a CNC machine tool.* ***Originality.*** *The defined basic principles of designing parts of engines and cars provide an opportunity to create a flexible spatial model and more fully automate the process of drawing up technical documentation. The developed mathematical spatial models of the supporting and working surfaces of the camshaft make it possible to write a control program with the determination of the optimal trajectory of the mutual movement of the part and the tool.* ***Practical value.*** *The obtained results can be recommended when designing car parts and assemblies.*

Key words: *computer simulation, mathematical modeling, spatial model, car, engine, software research, software analysis.*

Introduction

The development of automotive technology for various purposes, as well as the improvement of existing car models, requires a fast and flexible design process. Currently, the creation of parts and cars as a whole is carried out in design software products. At the same time, spatial models of parts and nodes are the starting point, and the necessary design documentation is performed on their basis. When improving a certain node, it is necessary to be able to quickly make changes to existing models. Thus, all elements must be created with flexibility and ease of editing in mind, which will be clearly reflected in the structure of the part file. In addition, it is desirable to have a toolkit and a defined sequence of initial inspection of parts for strength and other parameters. Also, when manufacturing parts on CNC machines, it is necessary to quickly obtain a control program that will ensure an increase in the accuracy of the product by ensuring the optimal trajectory of the mutual movement of the part and the tool. Therefore, the creation of a comprehensive methodology for the design of car parts, their basic inspection and obtaining design documentation is an important technical task.

Analysis of publications

Currently, in engineering, and in particular in the automotive industry, considerable attention is paid to computer-aided design methods of parts and assemblies. In work [1], general information on the features of engineering drawing and design is collected. The typical standards according to which technical documentation is drawn up are considered.

The paper [2] proposes ways of using modern computer support for the purpose of designing and modernizing various structures. Features of parametric modeling of internal combustion engines and features of design calculations in the Delcam PowerSHAPE system are considered in [3, 4]. In work [5], the main attention is paid to the description of the general principles of designing various engineering equipment. The features of using various CAD/CAE/CAM tools to solve applied problems are explained. In the works [6, 7] the basic concepts of design are expanded, product design modeling and the creation of integrated engineering systems are considered, and digital design technologies are considered.

Modern application software packages provide not only spatial modeling, but also basic engineering calculations. In [8, 9], the use of computer modeling for the purpose of researching the operation of equipment [8] and the parameters of system elements [9] is considered.

One of the most common methods of analyzing system operation is based on the use of the finite element method [10]. The work defines the basic theoretical provisions necessary for engineering analysis, as well as the toolkit of packages that provide research using this method. Practical recommendations for engineering analysis in the ANSYS system are given in [11]. In work [12], the method of performing frequency analysis in the SolidWorks system is given. Artificial intelligence systems, which are also used to optimize road transport parameters, are becoming widely used [13].

Methods of mathematical spatial modeling of various work surfaces and their processing processes also deserve considerable attention [14, 15].

Purpose and formulation of the task

The main goal of the work is to determine the rational sequence and basic principles of computer-aided design, research and manufacturing of car and engine parts.

To achieve this goal, it is necessary to note the main requirements for creating spatial models of parts and the features of software research of their properties. Determine the conditions for creating flexible parametric models. Specify ways to automate the creation of technical documentation. To carry out mathematical spatial modeling of the surfaces of the part in order to optimize control programs for CNC machines.

Spatial modeling of car and engine details

The object of research is the process of designing parts and assemblies of road transport. For example, consider the process of modeling the camshaft of the D-240 engine, the approximate drawing of which is shown in Figure 1. All constructions will be carried out in the SolidWorks software package.

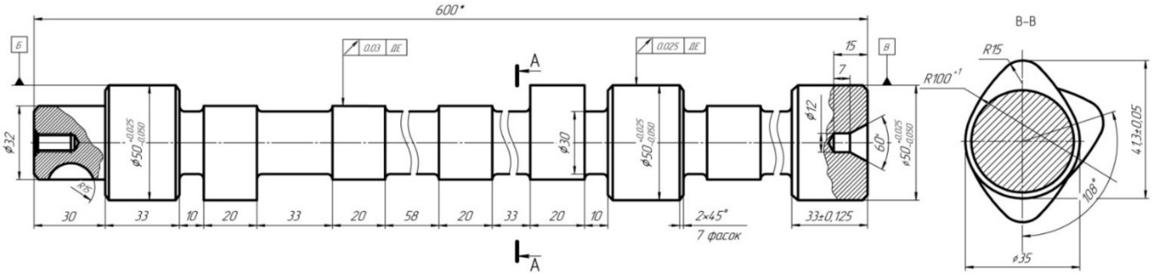


Fig. 1. Camshaft of the D-240 engine

The design of parts of car assemblies in modern mechanical engineering begins with spatial modeling. At the same time, it is important to create a flexible parametric model. This will enable quick editing when changing key dimensions and basic geometry. Also, the correct creation of a spatial model will facilitate obtaining a drawing with maximum automation of this process. In addition, it will be possible to receive a control drawing for editing the model.

When modeling all elements of cars, the following principles should be observed:

– bodies of rotation must be created with the help of the command "turned bosses";

– sketches must be defined by entering the minimum necessary number of dimensions and relationships between body elements;

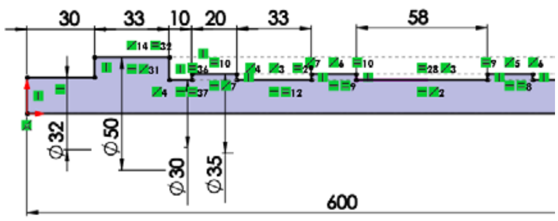
– when defining sketches, preference should be given to relationships, not dimensions;

– it is necessary to maintain the connection between successive sketches, by using relationships, the command "transform objects" and equations;

– the construction tree must contain the minimum necessary number of elements.

In addition, when creating complex parts with typical elements, as well as in the case of the layout of assembly nodes, it is advisable to create additional folders for the purpose of structuring and readability of the model tree. By following these principles, the model will be easy for any engineer to read and will respond correctly to changes.

Thus, the construction of the selected camshaft (Fig. 1), taking into account the above principles, will begin with the creation of a basic sketch (Fig. 2, a) and the application of the rotation operation (Fig. 2, b). Creating steps with a diameter of 35 mm determines the position of the cams on the camshaft and sets their minimum diameter. The use of collinearity and equality relationships makes it possible to simultaneously change the parameters of the base circles of the cams.

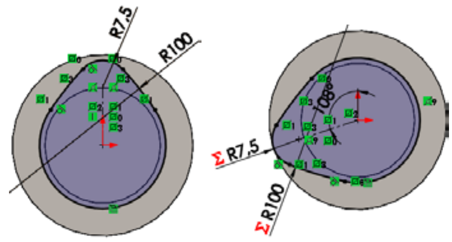


a)

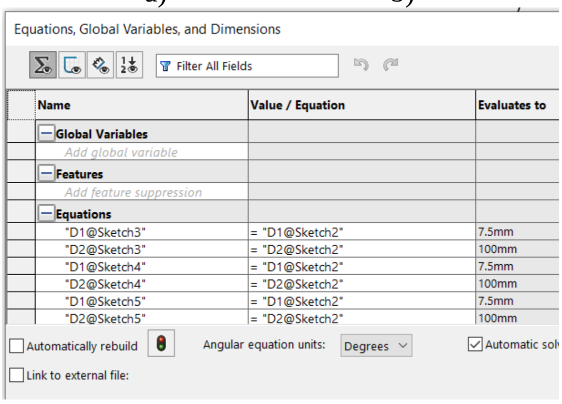
b)

Fig. 2. Basic operation of creating a camshaft model: a) – sketch of the operation; b) – result of execution

The profile of the cam is determined only for the first of them (Fig. 3, a), for all the following ones (Fig. 3, b), equations in the SolidWorks system are used (Fig. 3, c), which also makes it possible to simultaneously change the profile of all cams at the same time . When determining the dimensions of elements in the system, it is possible to mark auxiliary ones that do not need to be shown on the drawing.



a) b)



Equations, Global Variables, and Dimensions

Filter All Fields

Name	Value / Equation	Evaluates to
Global Variables		
Add global variable		
Features		
Add feature suppression		
Equations		
"D1@Sketch3"	= "D1@Sketch2"	7.5mm
"D2@Sketch3"	= "D2@Sketch2"	100mm
"D1@Sketch4"	= "D1@Sketch2"	7.5mm
"D2@Sketch4"	= "D2@Sketch2"	100mm
"D1@Sketch5"	= "D1@Sketch2"	7.5mm
"D2@Sketch5"	= "D2@Sketch2"	100mm

Automatically rebuild | Angular equation units: Degrees | Automatic sol

Link to external file:

c)

Fig. 3. Construction of cam profiles: a) – sketch for the first cam; b) – sketch for the following cams; c) – an equation in the SolidWorks system

The central holes of the shaft are obtained using a library of typical elements, which significantly speeds up the selection of parameters and further editing. Small elements such as chamfers and round-ups are created using appropriate commands, while all elements of the same size must be selected in one command (See, Fig. 4).

Fig. 4. Spatial model of the camshaft

Creating a drawing and marking the necessary dimensions in the SolidWorks system is carried out in a semi-automatic mode. Moreover, in order to display the control dimensions on the drawing (Fig. 5), when creating the model types, it is necessary to check the Import annotations option compatible with the Desing annotations command.

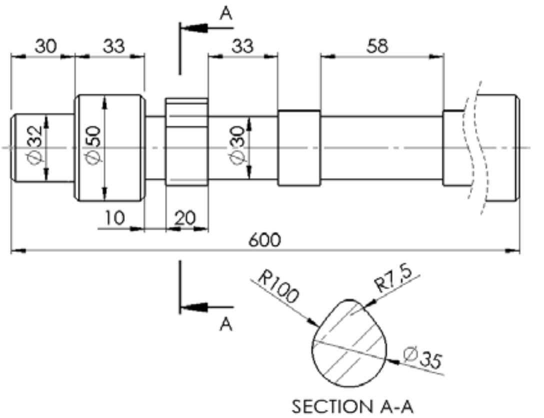


Fig. 5. Automatic creation of a camshaft drawing with the insertion of control dimensions

Similar requirements for creating spatial models are also relevant for other parts of cars and engines. It is also important in 3D modeling to determine the properties of elements and the document in general. For the correct calculation of mass and inertia characteristics, it is necessary to choose the type and brand of material. For the purpose of automatic filling of technical documentation, including the main inscription on the drawing, specifications and other documents, additional properties are also determined, for example, accuracy, roughness, description of the part, etc.

Basic model robustness check

At the design stage, it is necessary to conduct preliminary verification calculations. Modern software products offer a number of solutions. The most common is the static analysis of structures and elements. In addition, various dynamic, thermal, hydraulic and other studies are available. Of course, computer analysis cannot fully replace field tests, which remain mandatory for responsible parts, but allow to identify problem areas of parts and assemblies as a whole even at the design stage. Also, according to the results of the static analysis, optimization of the design of the part is carried out in order to rationally use the material and reduce the weight of the product. Most of these studies are also relevant for the automotive industry.

The initial information for the static calculation is the spatial model of the part. At the same time, it is mandatory to determine the material, conditions of fastening and load. The accuracy of the calculation is determined by the size of the mesh of finite elements (Fig. 6). As the grid size decreases, the accuracy of calculations increases, but the calculation time also increases, so excessive grid reduction is not rational.

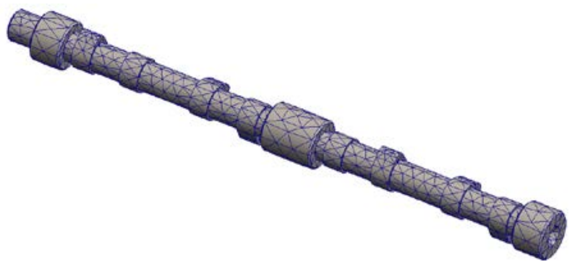


Fig. 6. Grid of finite elements of the camshaft

The SolidWorks Simulation system provides automatic determination of various types of load, including constant acting force, torque, distributed load, etc. In addition, different modes of determining the supporting elements and the method of their fixation are available.

During operation, the camshaft is fixed on the bearings installed on the support necks. The camshaft receives the torque from the timing belt and drives the intake and exhaust valves, depending on the function determined by the shape of the cams. These parameters determine the nature of fastening and loading of this part.

In the initial calculation, reducing the grid of finite elements is not advisable (Fig. 7), and it is built in automatic mode, it gives a satisfactory result.

As a result of the static calculation, it is possible to obtain a map of the stress distribution in the parts, a map of the movements of individual elements (Fig. 7). Moreover, to determine the coefficients of the safety margin and identify the most loaded areas.

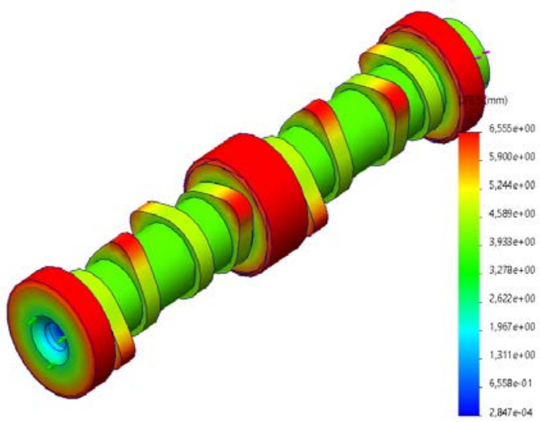


Fig. 7. Map of camshaft movements

It is also possible to optimize the model in automatic mode. At the same time, the program offers to change certain dimensions of the part, taking into account the user's settings.

Frequency analysis and determination of dynamic characteristics

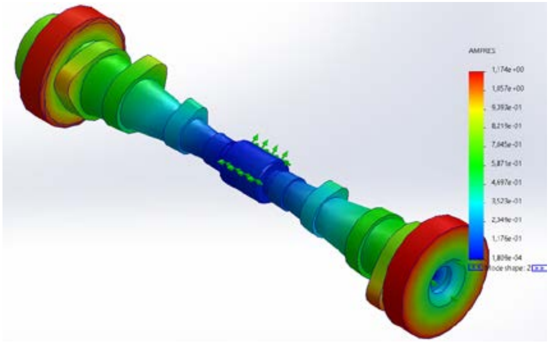
The camshaft works in rather difficult operating conditions and perceives variable dynamic loads. At the same time, it is also important to know one's own oscillation frequencies to prevent operation in a resonant mode. That is, for this type of details, it is relevant to conduct a dynamic study, in particular, a frequency analysis.

Frequency analysis in SolidWorks Simulation is also based on the spatial model of the shaft. At the same time, the influence of the size and configuration of the mesh of finite elements is similar to the static calculation (See, Fig. 6). Determination of natural frequencies of the shaft is carried out for the unloaded model, but with the specified method for fixing the part.

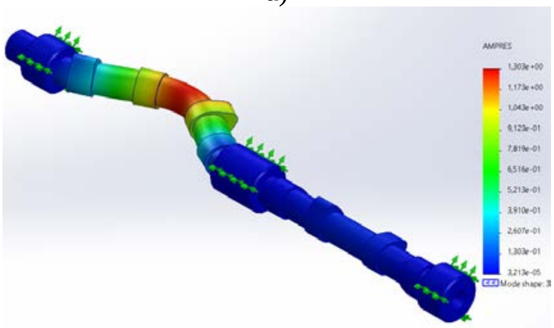
As a result of the frequency analysis, it is possible to obtain the values of the natural frequencies of oscillations of the part (Table 1), as well as the corresponding forms of oscillations (See, Fig. 8).

Table 1. Natural frequencies of camshaft oscillations

Own frequency number	rad/s	Hertz	Seconds
1	182,25	29,005	0,034476
2	11 927	1 898,3	0,00052678
3	14 283	2 273,2	0,00043991
4	14 319	2 279	0,00043879
5	14 332	2 281	0,00043841



a)



b)

Fig. 8. Forms of natural oscillations: a – for the 2nd natural frequency; b – for the 3rd natural frequency

Determination of transient and amplitude-phase-frequency characteristics is carried out according to the method given in [13]. In order to automate calculations, a calculation program was created in the Mathcad mathematical package. The initial data is the number of sections and their dimensions, including outer and inner diameters and length.

The equations of oscillations of the camshaft, as well as other parts of the car and engine assemblies, can be determined by differential equations with constant coefficients. Thus, the equation of motion of the oscillating system will have the following form

$$m \cdot y'' + h \cdot y' + c \cdot y = F \qquad (1)$$

where $m \cdot y''$ – inertia force; $h \cdot y'$ – damping force; $c \cdot y$ – elastic strength.

In order to solve this equation, it is necessary to introduce the notation

$$\frac{m}{c} = T^2, \ \frac{h}{c} = 2 \cdot \xi \cdot T = T_1, \ \frac{1}{c} = K_{cm}, \quad T = \frac{1}{\omega_0} = \sqrt{\frac{m}{c}}, \qquad (2)$$

where T – inertial time constant, s; $\omega_0 = \sqrt{\frac{c}{m}} = 2 \cdot \pi \cdot f_0$ – circular natural frequency of oscillations, c^{-1}; f_0 – natural frequency of oscillations of the system, Hz; T_1 – damping time constant, s; $\xi = \frac{h}{h_{крит}}$ – relative damping ratio; $\lambda = 2 \cdot \pi \cdot \xi$ – logarithmic decrement of oscillation damping; K_{cm} – static characteristics of the system, mm/N.

Considering equation (2), the function of the oscillating system (1) can be written in the form

$$T^2 \cdot y'' + 2 \cdot \xi T \cdot y' + y = K_{CT} \cdot F \qquad (3)$$

Let us differentiate the equation by time

$$y \cdot \left(T^2 \cdot p^2 + 2 \cdot \xi \cdot T \cdot p + 1\right) = K_{CT} \cdot F \qquad (4)$$

In this way, the equality of the transition process will have the form

$$y = K_{CT} \cdot F \cdot \left(1 - \frac{\omega_0}{\omega_1} \cdot e^{-\frac{\xi t}{T}} \cdot \sin\left(\begin{array}{l}\omega_1 t + \\ +arctg\,\dfrac{\omega_1 T}{\xi}\end{array}\right)\right) \quad (5)$$

In order to calculate the dynamic characteristics of the camshaft, it is necessary to calculate the coefficients contained in equation (5).

As it is known, the transfer function of an element or system can be defined as the ratio of the original $x_{вих}$ coordinate to the input $x_{вхід}$. That will in operator form look as

$$W(p) = \frac{x_{вих}}{x_{вхід}} = \frac{y(p)}{F(p)} = \frac{K_{CT}}{T^2 \cdot p^2 + 2 \cdot \xi \cdot T} \quad (6)$$

In equality (6), we replace the differentiation operator $\frac{d}{dt} = p$ for $j \cdot \omega$, which will allow to determine the frequency transfer function

$$W(\omega j) = \frac{K_{CT}}{1 - T^2 \cdot \omega^2 + j \cdot 2 \cdot \xi \cdot T \cdot \omega}. \quad (7)$$

Also, equation (7) can be written in the form

$$W(\omega j) = \mathrm{Re}(\omega) + j \cdot \mathrm{Im}(\omega), \quad (8)$$

where

$$\mathrm{Re}(\omega) = \frac{K_{CT} \cdot (1 - T^2 \cdot \omega^2)}{(1 - T^2 \cdot \omega^2)^2 + (2 \cdot \xi \cdot T \cdot \omega)^2}, \quad (9)$$

$$\mathrm{Re}(\omega) = \frac{K_{CT} \cdot (1 - T^2 \cdot \omega^2)}{(1 - T^2 \cdot \omega^2)^2 + (2 \cdot \xi \cdot T \cdot \omega)^2}. \quad (10)$$

Therefore, the dynamic compliance can be determined

$$A(\omega) = \sqrt{\mathrm{Re}^2 + \mathrm{Im}^2} = -\frac{K_{CT}}{\sqrt{(1 - T^2 \cdot \omega^2)^2 + (2 \cdot \xi \cdot T \cdot \omega)^2}}. \quad (11)$$

Phase angle

$$\varphi(\omega) = arctg\,\frac{\mathrm{Im}}{\mathrm{Re}} = -arctg\,\frac{2 \cdot \xi \cdot T \cdot \omega}{1 - T^2 \cdot \omega^2}. \quad (12)$$

Taking into account the general layout of the selected camshaft, it can be conditionally divided into 22 sections. Moreover, each section of the shaft will be determined by its length, average outer and inner diameters.

The mass of the plots is calculated according to the following formulas

$$V_i = l_i \cdot \pi \cdot \frac{D_i^2 - d_i^2}{4},\ V_s = \sum_i V_i, \quad m_s = \rho \cdot V_s \cdot 10^{-3}, \quad (13)$$

where V_i – the volume of the *i*-th plot, mm^3; D_i, d_i – average outer and inner diameters, mm; l_i – the length of the selected section, mm; ρ – density of the material of the part, gr/mm^3; m_s – total weight of the camshaft, kg.

Similarly, for each of the sections, the moment of inertia can be determined according to the known formula

$$I_i = \pi \cdot \frac{D_i^4 - d_i^4}{64}, \quad (14)$$

at the same time, the total moment of inertia of the camshaft will be defined as the arithmetic mean

$$I_s = \frac{\sum_i I_i}{i}. \quad (15)$$

On the basis of the described dependencies, the general form of the transient characteristic function (See, Fig. 9), amplitude-frequency (See, Fig. 10), and amplitude-phase-frequency characteristic of the camshaft (See, Fig. 11) was obtained.

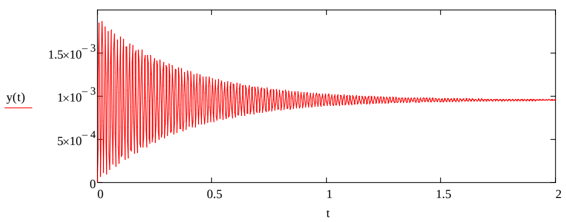


Fig. 9. Transient characteristics of the camshaft

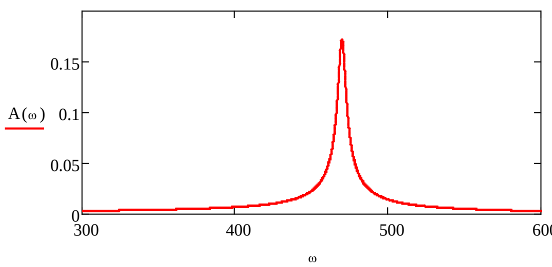


Fig. 10. Amplitude frequency characteristics of the camshaft

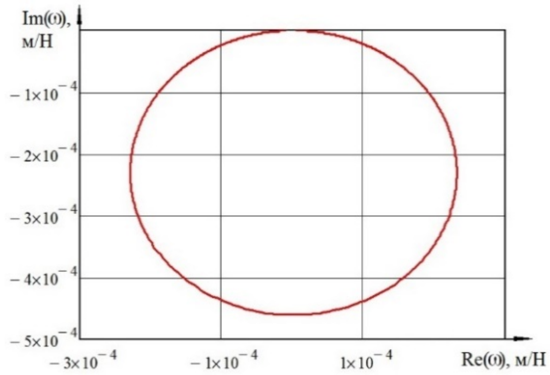


Fig. 11. Amplitude-phase-frequency characteristics of the camshaft

Thus, the sequential determination of natural oscillation frequencies in the SolidWorks Simulation system and frequency characteristics in the Mathcad mathematical package makes it possible to determine the conditions of steady operation of the camshaft. The proposed method can also be used for other parts of cars and engines.

Mathematical modeling of camshaft surfaces

On the basis of the developed spatial model of parts, the control code for their production on CNC machines is automatically obtained. For code generation, you can use SolidCam software or other typical packages. At the same time, it is necessary to import the model into the selected application, determine the type of processing, tools and, if necessary, adjust the cutting modes. Existing software solutions are unified, and therefore work perfectly when processing simple parts. At the same time, in the case of milling or grinding of parts with a complex shape, it is not always possible to obtain rational relative trajectories of the movement of the part and the tool during processing. To optimize the cutting process and improve the quality of the final product, it is necessary to carry out spatial mathematical modeling. The control code obtained in this way will significantly improve the parameters of the processed camshaft.

Cylindrical surfaces of support necks and curved surfaces of cams deserve the greatest attention when manufacturing camshafts. At the same time, the accuracy of the manufacturing of the support necks affects the correct location of the part in the node and the absence of knocking during the operation of the car engine. In addition, the accuracy of the profile of the cams is responsible for the correct cycle of the engine, that is, the timely supply of the mixture and the release of exhaust gases.

The final treatment of such surfaces is grinding. This ensures not only high profile accuracy, but also the necessary roughness of working and support surfaces. In order to optimize the control programs [15], it is advisable to determine the trajectory of the tool movement only taking into account the shape of the part, while the center of the tool will move equidistant to the profile of the surface being processed, and its dimensions will not affect the structure of the control program.

For the purpose of mathematical spatial modeling of the supporting and working surfaces of the camshaft, we will use the mathematical apparatus of transformation of coordinate matrices and known modules. In this way, the support neck of the camshaft will be described by a cylindrical module. Therefore, the equation of its surface has the form

$$C^{d}_{\theta_{sh},z,y_{sh}} = M1(z)\cdot M6(\theta_{sh})\cdot M2(y_{sh})\,, \qquad (19)$$

where z – the current coordinate along the camshaft axis, mm; θ_{sh} – the current angle that determines the point on the profile of the support neck of the shaft, rad; y_{sh} – the radius of the support neck of the camshaft, mm; *M1*, *M2*, *M6* – coordinate transformation matrices, and matrices *M1* and *M2* determine the linear movement along the *x* and *y* axes, respectively. Moreover, the matrix *M6* simulates the rotation of the initial vector around the axis z.

A graphic display of the surface of the camshaft support neck is shown in Figure 12.

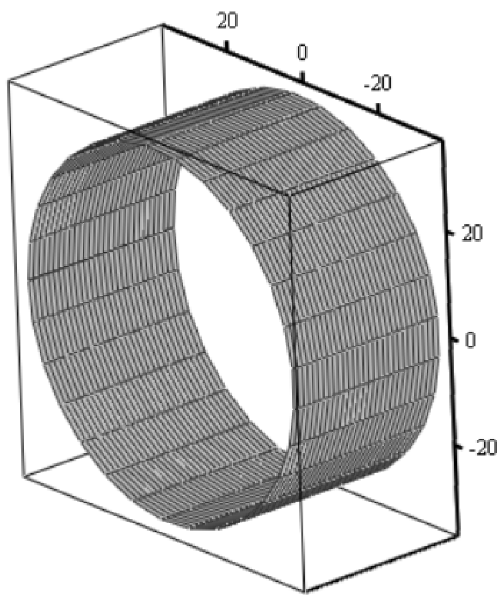


Fig. 12. Mathematical spatial model of the support neck of the crankshaft

When processing the profile of the cam with a cylindrical tool, including a grinding wheel, its profile is formed by rolling the cutting surface (See, Fig. 13), while the surface of the cam is tangent to the successive positions of the grinding wheel.

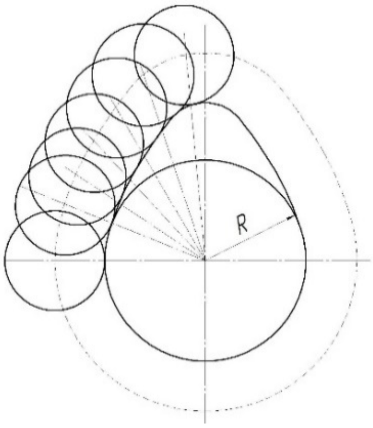


Fig. 13. Formation of the cam profile by rolling

Therefore, when the center of the tool moves with a radius R_t along a curve that is equidistant to the surface of the cam and is at a distance R_t from it, the profile of the part is determined by successive instantaneous positions of the grinding wheel.

The curvilinear profile line of the camshaft cam can be conditionally divided into 6 sections (See, Fig. 14, 15) with different radii and centers of curvature. The trajectory of the tool, which processes the profile of the part, relative to the curved surface of the cam has the form of an equidistant curve to its surface. At the same time, in the 1st and 6th sections, where the radius of curvature of the cam coincides with the center of rotation of the camshaft, the current coordinate of the center of the position of the equidistant curve can be determined from the equations

$$C_x(\theta) = L\cdot\sin(\theta),\ C_y(\theta) = -L\cos(\theta),$$
$$C(\theta) = \sqrt{[C_x(\theta)]^2 + [C_y(\theta)]^2}, \qquad (20)$$

where $C_x(\theta)$, $C_y(\theta)$ – the coordinates of the current equidistant points along the coordinate axes depending on the angular parameter of the camshaft cam θ, mm; $C(\theta)$ – the radius vector of the current equidistant point in the polar coordinate system, mm; $L = r + R_t$ – equidistant radius for the cam section, mm; r – the radius of the cam section, mm; R_t – cutter radius, mm.

For areas of the cam, where the center of the radial edge does not coincide with the center of rotation of the camshaft, the position equidistant to the profile is determined from the equality

$$R(\theta) = \sqrt{X_{yc}{}^2 + L^2 - 2\cdot X_{yc}\cdot L\cdot\cos(\gamma(\theta))},$$
$$R_x(\theta) = L\cdot\sin(\gamma(\theta)), \qquad (21)$$
$$C_y(\theta) = -L\cos(\gamma(\theta)),$$

where $\gamma(\theta)$ – the current angle of inclination of the radius vector to the current equidistant point (Fig. 14), rad.

General equidistant equation (Fig. 16)

$$\begin{aligned} R(\theta) = {} & C1(\theta)\cdot(1-\Phi(\theta-\theta1)) + \\ & + C2(\theta)\cdot(\Phi(\theta-\theta1)-\Phi(\theta-\theta2)) + \\ & + C3(\theta)\cdot(\Phi(\theta-\theta2)-\Phi(\theta-\theta3)) - \\ & + C4(\theta)\cdot(\Phi(\theta-\theta3)-\Phi(\theta-\theta4)) + \\ & + C5(\theta)\cdot(\Phi(\theta-\theta4)-\Phi(\theta-\theta5)) - \\ & + C6(\theta)\cdot\Phi(\theta-\theta5), \end{aligned} \qquad (21)$$

where $\theta1, \theta2 ... \theta5$ – angles that determine the position of the corresponding sections on the cam profile of the camshaft, rad.

Figure 15 shows the flat profile line of the camshaft cam. At the same time, the trajectory of the center of the grinding tool is shown in Figure 16.

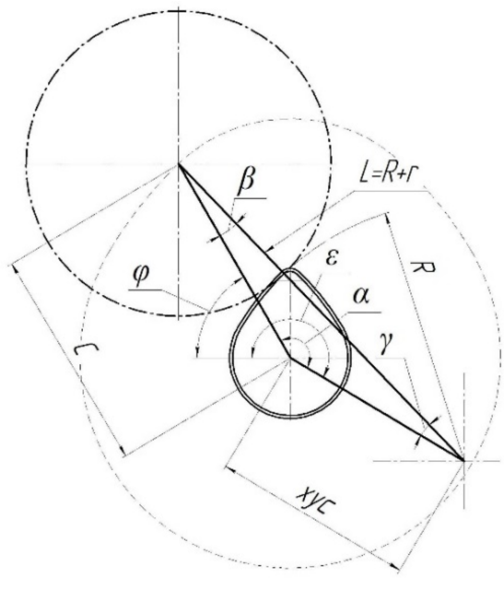


Fig. 14. Scheme for determining the profile of the cam

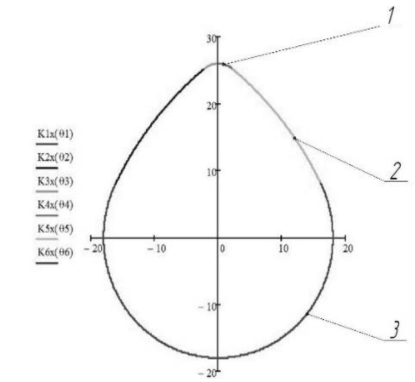


Fig. 15. The cam profile is described by a mathematical model

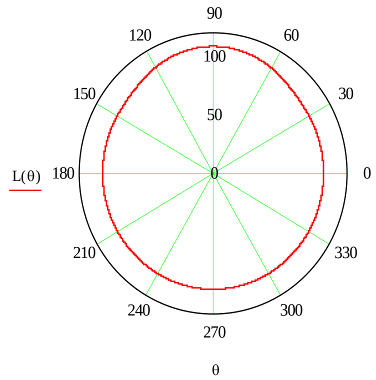


Fig. 16. Curve of movement of the center of the grinding wheel relative to the surface of the cam

The mathematical spatial model of the cam profile (Fig. 17) is constructed similarly to the surface of the support neck (19), however, when constructing a cylindrical surface, the movement along the *y* coordinate is constant and is determined by the radius of the support neck, and when constructing a curved surface of the cam, this value is variable and depends on the angular coordinates of the profile of the part.

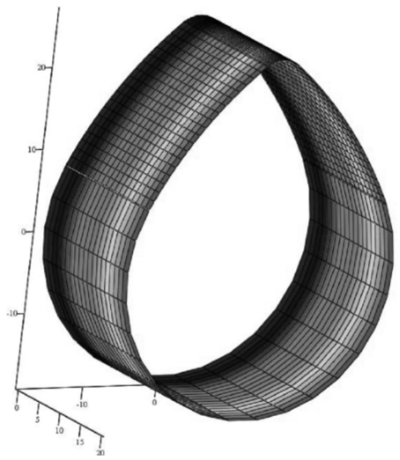


Fig. 17 Curve of movement of the center of the grinding wheel relative to the surface of the cam

Based on the developed mathematical models of support necks and camshaft cam, the control program for the CNC machine tool is determined. Which, in comparison with the automatically generated codes, will provide higher quality and accuracy of the camshaft surfaces of the internal combustion engine.

Conclusions

A comprehensive methodology for designing parts of engines and cars is proposed. The main principles of creating spatial models have been determined, in order to achieve their flexibility and simple editing. Methods of automating the development of drawings and design documentation are described. The software options for the primary verification of static strength and frequency analysis are considered.

On the example of the camshaft of a car engine, spatial modeling of the part was carried out. Static and frequency analysis of the part was carried out using the SolidWorks software product. Transient and amplitude-phase-frequency characteristics were determined using the program created in the Mathematical package Matchad. Based on the results of the calculations, the model is optimized and the conditions of stable operation are determined.

We will conduct mathematical spatial modeling of typical surfaces of the camshaft, with the aim of further research and optimization of the development of a control program for processing on a CNC machine tool.

References

1. C.Simmons, D.Maguire & N.Phelps (2020). *Manual of Engineering Drawing*.
2. О. В. Архіпов, К. В. Масляєв, Д. О. Ланцов (2018). Параметричне комп'ютерне моделювання в дизайні автомобільних вузлів та агрегатів. *Прикладна геометрія та інженерна графіка: міжвід. наук.-техн. зб.*, Київ. нац. ун-т будова і архіт., 94, 3- 7. O. V. Arkhipov, K. V. Masliaiev, D. O. Lantsov (2018). Parametrychne kompiuterne modeliuvannia v dyzaini avtomobilnykh vuzliv ta ahrehativ. [Parametric computer modeling in the design of automotive components and aggregates] *Prykladna heometriia ta inzhenerna hrafika: mizhvid. nauk.-tekhn. zb.*, Kyiv. nats. un-t budova i arkhit., 94, 3-7.
3. Chang, C.C. (2004). Direct slicing and G-code contour for rapid prototyping machine of UV resin spray using PowerSOLUTION macro commands. *Int J Adv Manuf Technol* 23, 358–365 https://doi.org/10.1007/s00170-003-1575-4

4. Якушенко, С.О., Носов, П.С. (2013). Проектні розрахунки та 3D моделювання двигунів внутрішнього згоряння у САПР Delcam PowerShape. *Інформ. технології в освіті, науці та вир-ві*. 4 (5). 165-179. Yakushenko, S.O., Nosov, P.S. (2013). Proektni rozrakhunky ta 3D modeliuvannia dvyhuniv vnutrishnoho zghoriannia u SAPR Delcam PowerShape. [Design calculations and 3D modeling of internal combustion engines in CAD Delcam PowerShape] *Inform. tekhnolohii v osviti, nautsi ta vyr-vi*. 4 (5). 165-179 http://dspace.opu.ua/jspui/handle/123456789/2687
5. Kuang-Hua Chang (2013) *Product Performance Evaluation using CAD/CAE.*
6. Kuang-Hua Chang (2016). *e-Design*.
7. Kuang-Hua Chang (2014). *Product Design Modeling using CAD/CAE.*
8. Кириченко І.Г, Черніков О.В., Роговий А.С., Рагулін В.М., Рєзніков О.О., Табуров О.С. (2021). Особливості комп'ютерного моделювання та дослідження режимів роботи елементів піднімальної платформи. *Вісник Харківського національного автомобільно-дорожнього університету.*, 95. 143-148. Kyrychenko I.H, Chernikov O.V., Rohovyi A.S., Ragulin V.M., Rieznikov O.O., Taburov O.S. (2021). Osoblyvosti kompiuternoho modeliuvannia ta doslidzhennia rezhymiv roboty elementiv pidnimalnoi platformy. [Peculiarities of computer modeling and study of operating modes of elements of the lifting platform] *Visnyk KhNADU.*, 95. 143-148.
9. Рагулін В.М., Ярижко О.В., Назарько О.О. (2022). Комп'ютерне моделювання як метод та засіб удосконалення будівельних машин. *Міжвідомчий науково-технічний збірник "Прикладна геометрія та інженерна графіка".* 102. 181–187. Ragulin V.M., Yaryzhko O.V., Nazarko O.O. (2022). Kompiuterne modeliuvannia yak metod ta zasib udoskonalennia budivelnykh mashyn. [Computer modeling as a method and means of improving construction machines] Mizhvidomchyi naukovo-tekhnichnyi zbirnyk "Prykladna heometriia ta inzhenerna hrafika". 102. 181–187.
10. Zhuming Bi (2017) *Finite Element Analysis Applications*.
11. Mary Thompson, John Thompson (2017) *ANSYS Mechanical APDL for Finite Element Analysis*.
12. Сіра Н.М., Кологойда А.В., Литвин О.О. & Кальченко Д.В. (2019) Дослідження динамічних характеристик при чистовому шліфуванні циліндричної та голчастої поверхонь валика текстильної машини. *Технічні науки та технології*. 2 (16), 44-53. Sira N.M., Kolohoida A.V., Lytvyn O.O. & Kalchenko D.V. (2019) Doslidzhennia dynamichnykh kharakterystyk pry chystovomu shlifuvanni tsylindrychnoi ta holchastoi poverkhon valyka tekstylnoi mashyny. [Study of dynamic characteristics during clean grinding of the cylindrical and needle surface of the rollers of a textile machine.] *Tekhnichni nauky ta tekhnolohii*. 2 (16), 44-53.
13. Badra J., Pal P. & Som S. (2022) *Artificial Intelligence and Data*. https://doi.org/10.1016/C2020-0-03091-4
14. Kalchenko V.V., Kalchenko V.I., Tsybulya S.D., Kolohoida A.V., Sakhno Ye.Yu.. (2022). Simulation of the process of milling and grinding cylindrical surfaces by an oriented tool in one setup. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, 4, 66 – 70. https://doi.org/10.33271/nvngu/2022-4/066
15. Kalchenko, V., Kalchenko, V., Sira, N., Kalchenko, O., Vynnyk, V., Kalchenko, D., & Morochko, V. (2020). Development of the single-setup milling process model of the shaft support necks and cams. *Eastern-European Journal of Enterprise Technologies,* (4), 48-54. https://doi.org/10.15587/1729-4061.2020.208579

Kalchenko Volodymyr[1], Doctor of Technical Sciences, Professor Department of Road Transport and Industrial Engineering,
e-mail: vvkalchenko74@gmail.com,
Phone: +38095-893-78-74,
ORCID: https://orcid.org/0000-0002-9072-2976
Kolohoida Antonina[1], PhD, Department of Road Transport and Industrial Engineering,
e-mail: kolohoida@gmail.com,
Phone: +38068-44-125-20,
ORCID: https://orcid.org/0000-0002-1742-2686
Pasov Gennadiy[1], PhD, Department of Road Transport and Industrial Engineering,
e-mail: genapasov@gmail.com ,
Phone: +38050-14-808-74,
ORCID: http://orcid.org/0000-0001-7248-9085
Sira Nataliia[1], PhD, Department of Road Transport and Industrial Engineering,
e-mail: nnseraya@gmail.com ,
Phone: +38093-76-505-85,
ORCID: https://orcid.org/0000-0002-6242-5210
Klymenko Valeriy[2], DSci (Eng.), Prof., Head of Departament of Automobiles named after A.B. Gredeskul,
e-mail: valeriy.klimenko@gmail.com,
Phone.: +38(050) 845-65-29,
ORCID: http://orcid.org/0000-0002-7399-0397
[1]Chernihiv Polytechnic National University Shevchenko str., 95, Chernihiv, Ukraine, 14035
[2]Kharkiv National Automobile and Highway University, Yaroslava Mudrogo str., 25, Kharkiv, Ukraine, 61002

Комп'ютерне моделювання та програмне дослідження деталей автомобілів та двигунів

Анотація. Проблема. *Розвиток автомобільної техніки різного призначення, а також вдосконалення існуючих моделей автомобілів,* *вимагає швидкого та гнучкого процесу проектування. Вихідними при проектуванні є просторові моделі деталей та вузлів, а на їх базі виконують необхідну конструкторську документацію. При виготовленні деталей на верстатах з ЧПК необхідно швидко отримувати керуючу програму, яка забезпечить підвищення точності виробу за рахунок забезпечення оптимальної траєкторії взаємного переміщення деталі та інструменту. Отже, створення комплексної методики проектування деталей автомобілів, їх базової перевірки та отримання конструкторської документації є важливою технічною задачею.* ***Мета.*** *Головною метою роботи є визначення раціональної послідовності та основних принципів комп'ютерного проектування, дослідження і виготовлення деталей автомобілів й двигунів. А також розробка математичних просторових моделей поверхонь з метою оптимізації керуючих програм для верстатів з ЧПК.* ***Методологія***. *Прийняті в роботі підходи до вирішення поставленої мети базуються на загальних конструкторських принципах. Методах проведення статичного та динамічного розрахунків, а також просторового математичного моделювання процесів виготовлення деталей.* ***Результати.*** *Розроблено комплексну методику проектування деталей двигунів та автомобілів. Визначено основні принципи створення просторових моделей, для досягнення їх гнучкості та простого редагування. Описано методи автоматизації розробки креслень та конструкторської документації. Розглянуто програмні можливості, щодо первинної перевірки статичної міцності та частотного аналізу. Розроблено розрахункову програму для побудови перехідної та амплітудно-фазово-частотну характеристик. Проведемо математичне просторове моделювання типових поверхонь розподільного валу, з метою подальшого дослідження та оптимізації розробки керуючої програми для обробки на верстаті з ЧПК.* ***Оригінальність.*** *Визначені базові принципи проектування деталей двигунів та автомобілів дають можливість створення гнучкої просторової моделі, й більш повної автоматизації процесу оформлення технічної документації. Розроблені математичні просторові моделі опорних та робочих поверхонь розподільного валу дають можливість написання керуючої програми з визначенням оптимальної траєкторії взаємного переміщення деталі та інструменту.* ***Практичне значення***. *Отримані результати можуть бути рекомендовані при проектуванні деталей та вузлів автомобілів.*

Ключові слова: *комп'ютерне моделювання, математичне моделювання, просторова модель, автомобіль, двигун, програмне дослідження, програмний аналіз.*

Кальченко Володимир Віталійович[1], д.т.н., професор кафедри автомобільного транспорту та галузевого машинобудування,
e-mail: vvkalchenko74@gmail.com,
тел.: +38095-893-78-74,
ORCID https://orcid.org/0000-0002-9072-2976
Кологойда Антоніна Вікторівна[1], к.т.н., доцент кафедри автомобільного транспорту та галузевого машинобудування,
e-mail: kolohoida@gmail.com,
тел.: +38068-44-125-20,
ORCID https://orcid.org/0000-0002-1742-2686
Пасов Генадій Володимирович[1], к.т.н., доцент кафедри автомобільного транспорту та галузевого машинобудування,
e-mail: genapasov@gmail.com,
тел.: +38050-14-808-74,
ORCID: http://orcid.org/0000-0001-7248-9085
Сіра Наталія Миколаївна[1]**,** к.т.н., доцент кафедри автомобільного транспорту та галузевого машинобудування,
e-mail: nnseraya@gmail.com,
тел. +38093-76-505-85,
ORCID: https://orcid.org/0000-0002-6242-5210
Клименко Валерій Іванович[2], д.т.н., проф., зав. кафедри автомобілів ім. А. Б. Гредескула,
e-mail: valeriy.klimenko@gmail.com,
тел.: +38(050) 845-65-29,
ORCID: http://orcid.org/0000-0002-7399-0397

[1]Національний університет «Чернігівська політехніка», вул. Шевченко, 95, м. Чернігів, Україна, 14035.
[2]Харківський національний автомобільно-дорожній університет, вул. Ярослава Мудрого, 25, м. Харків, Україна, 61002.