Programming While Construction of Engineering 3D Models of Complex Geometry

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Abstract. The capabilities of geometrically accurate computational 3D models construction with the use of programming are presented. The construction of models of an architectural arch and a globoid worm gear is considered as an example. The models are designed in the AutoCAD package. Three programs of construction are given. The first program is for designing a multi-section architectural arch. The control of the arch’s geometry by impacting its main parameters is shown. The second program is for designing and studying the working surface of a globoid gear’s worm. The article shows how to make the animation for this surface's formation. The third program is for formation of a worm gear cavity surface. The cavity formation dynamics is studied. The programs are written in the AutoLisp programming language. The program texts are provided.

1. Introduction
Nowadays 3D modeling is a general design method of engineering activity. Drawing becomes secondary to the virtual and realistic 3D models of elements, units, buildings and constructions [1,2].

An efficient method for constructing and studying 3D models of complex form is programming. Among publicly available CAD packages (AutoCAD, SolidWorks, Kompas), programming is more developed in AutoCAD package in AutoLisp language. AutoLisp has an extensive literature [3-6].

Among advantages of the models designed on the basis of software realization, there are: automated control of the model’s form, high accuracy [7], and performing constructions along with complex analytic and geometric calculations. Programming makes it possible to create models which are very time-consuming when constructed by hands.

The author actively uses programming in the language of AutoLisp to construct and study complex geometric models [2,8-13].

The objective of this work is to demonstrate possibilities of programming while designing and studying geometric 3D models.

Three examples are given. The first example is a program for constructing an architectural arch model [14-16]. The program is associated with a training course for students of the construction specialty. Two other examples relate to scientific studies of the geometric shape of complex objects. This is a study of the surface of a globoid worm gear.

Research work is done in AutoCAD package, programming language is AutoLisp.
2. Architectural arch

Arch consists of sections located by a circular massive. In a real object, the surface of a section is part of a hyperbolic paraboloid [14,15]. In program 1, this surface is replaced by a simpler surface of a parabolic cylinder [14,17,18].

Main parameters of the model are shown in Figure 1(a). The surface of a section is formed by moving parabola \( p a r \) along a rectilinear trajectory \((p1, p2)\). In program, the main functions for arch con-

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\begin{array}{l}
\text{Table 1. Program. Building an architectural arch.}
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Construction are given: arch, shell, parabola. Values of parameters are set by dataset function. In order to increase visibility of the model, the simulation of construction (constr function) and of glazing (glazing function) is provided.

The program is educational. Students master AutoLisp, create additional functions of (constr) and (glazing), develop examples of arches.

![Scheme and variants of the arch.](image)

**Figure 1.** Scheme and variants of the arch.

In Figure 1(b–f), typical examples of arch are given. For all the examples \( r = 25 \). Values of other parameters are as follows. For Figure 1(b): \( h = 30; \, \text{gam} = 30; \, h1 = 15; \, h2 = 0; \, ns = 6; \, \text{del} = 0.3; \, e = 5 \). For 1(c): \( h = 30; \, \text{gam} = 0; \, h1 = 30; \, h2 = 0; \, ns = 3; \, \text{del} = 1; \, e = 5 \). For 1(d): \( h = 50; \, \text{gam} = 30; \, h1 = 35; \, h2 = –8; \, ns = 2; \, \text{del} = 1; \, e = \text{nil} \). For 1(e): \( h = –5; \, \text{gam} = –30; \, h1 = 10; \, h2 = 10; \, ns = 7; \, \text{del} = 0.3; \, e = 1 \). For 1(f): \( h = 20; \, \text{gam} = 0; \, h1 = 30; \, h2 = 5; \, ns = 4; \, \text{del} = 0.3; \, e = 3 \).

![Globoid worm gear set and its workpiece.](image)

**Figure 2.** Globoid worm gear set and its workpiece.

### 3. Globoid worm surface research

The construction of geometrically accurate models of a cutter is shown in the research paper [2,9,10]. One of the models is the globoid worm gear set model, which is taken as an example for studying the programming application while constructing complex models, see Figure 2. The model objective is to study geometrical configuration and constructing computational geometric patterns for construction accuracy control [19].

A workpiece of the worm in a globoid gear has the form of the inner surface of a circular torus, see Figure 2 [2]. The worm tooth section outline in a plane which passes through the worm axis has the
shape of an equilateral trapezium $k$, see Figure 3(a,b). The tooth surface is formed by the moving segments of the trapezium’s lateral sides. Each segment carries out double movement: rotation around axis of the worm $i_1$ at a velocity $\omega_1$ and simultaneous rotation around axis of the worm gear $i_2$ at a velocity $\omega_2$. As a result, a beautiful kinematic surface is formed.

![Figure 3](image)

**Figure 3.** Globoid worm bearing surface work.

In order to study this surface, a Program [2] which implements the described pattern-generation algorithm is elaborated. When segment $b$ is determined as the offsetting object, section $S$ of the surface is formed, see Figure 3(c). This surface has axis $i_1$. Section plane $(i_1, O_2)$, see Figure 3(d) shows, that all the generators of surface $S$ are tangent lines to the torus (tor), which has $i_1$ axis and a generatrix – the $d_p$ circumference. Plane section $\gamma$ detects a family of lines; the envelope line of this family is the leminiscate of Bernoulli, see Figure 3(f).

The program [2] allows to create animation of the surface formation. A set of files consisting of 400 frames is obtained. In order to improve visualization, a torus is constructed beforehand, see Figure 4. After that, a single file of continuous animation is composed out of the set of jpg-files.

4. **Globoid worm design**

After choosing A or B point mark as the rotational object, we deduce the movement pattern of this point in a shape of h 3D helix, see Figure 5(a). The helix is formed by the surface movement of the point over globoid of the tor* worm, see Figure 5(b).

![Figure 4](image)

**Figure 4.** Animation frames: a – frame 2; b – 37; c –100; d – 200; e – 300; f – 350. Frame 400 – see Figure 3(c).

If we point the $k$ segment of a side of the trapezoid, a narrow section $S^*$ of $S$ surface is created. It is one of the worm’s tooth surfaces, formed by the segment movement along the $h$ trajectory.

To build a tooth worm, you must specify the entire contour $k$. A set of contour lines arranged along the trajectory $h$ is formed, see Figure 5(c). The program creates the body, see Fig. 5 (d). After uniting
the body with the worm’s template and removing protuberances at the edges, a body of the worm is formed, see Figure 2(a).

5. The surface of the cavity of the globoid wheel
A worm gear is formed by milling of the gear workpiece, see Figure 2(b) with a worm hob [2]. Equally spaced pitches of the same shape are formed on the gear.

![Figure 5. Worm thread construction.](image)

A cavity surface research is an interesting task, which allows to study dynamics of the milling process, and to elaborate supervisor programs for processing units equipped with program control.

Complexity of the milling process does not allow implementing analytical research methods. So we create a geometrical model, reproducing the milling process.

In the proposed model, a worm hob is replaced by a special worm, see Figure 6(a). Considering requirements to the worm gear operation, clearances $\Delta_1, \Delta_2$ and curving by radius $r$ are imparted to the special worm’s tooth profile $k^*$, see Figure 6(b) compared to profile $k$, see Figure 3 (b) A sector corresponding with one pitch is cut out of the gear, see Figure 6(c,d). Hollow surface is formed by conformal step-by-step rotation of the worm and the gear sector. At each step, the worm volume is deducted from the gear sector. Step-by-step rotation is performed by Program [2].

The worm and the gear sector are produced beforehand. They are placed in Position 1, see Figure 6(a), Figure 3(a), and determined at the program’s request. The program switches the sector and the worm to Position 2. Conformal step-by-step rotation of the worm and the sector along with the worm volume deduction from the sector begins. Rotation cycle is finished in Position 3. After that, the worm and the sector with created pitch are returned to Position 1, see Figure 7(a).

![Figure 6. Scheme of the construction of the cavity.](image)
6. Investigation of the wheel cavity
After executing the program, a wheel cavity as in the figure, see Figure 7(b). After finishing construction of cross sections of the surface, we obtain its visual framework, which is suitable for determining coordinates of the surface points automatically, see Figure 7(c).

In the process of cavity construction, complex geometrical measurements and calculations can be performed. Cavity volume $V$ change depending on the angle $\phi$ of a sector rotation can be set as an example, see Figure 6(a), Figure 8. Measurements showed that the biggest volume of metal is removed from a cavity after the initial 5 to 7 degrees of the sector rotation, that indicates a heavy workload on the worm hob ends.

![Figure 7. The surface of the cavity of the globoid wheel.](image)

7. Conclusion
3D modeling software allows successfully solve complicated tasks of geometric modeling. Software programs for geometrical construction can be comparatively simple, and comprehensible even for inexperienced users.

The author recommends using AutoLisp programming language in AutoCAD package. This programming language is easy to master; the programs possess high operational speed. For example, building an arch with program in 2-3 seconds, a set of 400 raster frames for a kinematic surface animation file is generated by program [2] within 3-4 hours. To create a graph, you need the same amount of time, see Figure 8.

It is important to implement programming of geometric models in the educational process of different universities. Nowadays Graphics Departments can only teach students how to construct simple 3D models. Computer programming education can significantly increase the level of training among students. Reserves of time can be found with the reduction of obsolete educational disciplines [20, 21].

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