Application of Computer Technologies in Building Design by Example of Original Objects of Increased Complexity

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Abstract. The article deals with the solution of problems in AutoCAD offered at the All-Russian student Olympiads at the section of "Computer graphics" that are not typical for the students of construction specialties. The students are provided with the opportunity to study the algorithm for solving original tasks of high complexity. The article shows how the unknown parameter underlying the construction can be determined using a parametric drawing with geometric constraints and dimensional dependencies. To optimize the mark-up operation, the use of the command for projecting the points and lines of different types onto bodies and surfaces in different directions is shown. For the construction of a spring with a different pitch of turns, the paper describes the creation of a block from a part of the helix and its scaling when inserted into a model with unequal coefficients along the axes. The advantage of the NURBS surface and the application of the "body-surface-surface-NURBS-body" conversion are reflected to enhance the capabilities of both solid and surface modeling. The article's material introduces construction students into the method of constructing complex models in AutoCAD that are not similar to typical training assignments.

1. Introduction
At the Olympiads, held in Moscow State University of Fine Chemical Technologies named after M.V. Lomonosov (MITHT) in 2015-2016 [1], the offered assignments were not designed for students of construction specialties. Their study assignments on engineering and computer graphics [2], therefore, knowledge and skills have their own specifics and in many respects differ from machine builders.

All-Russia Olympiads in computer graphics have become popular. The issues of their organization, carrying out [1, 3-12] and analyzing the solution of problems [13,14] are constantly highlighted in the press. The proposed article aims to familiarize construction students with the algorithm for solving original olympiad problems, based on solid and surface modeling used in construction design. The material of the article gives the notion that in order to determine the unknown element, it is necessary to construct a parametric drawing with geometric constraints and dimensional dependencies. Students need to be able to use blocks as a tool for fast editing of drawings, a tool for scaling with different coefficients in the axes and the possibility of reducing the size of the file. To expand the modeling capabilities, it is necessary to use the body-surface-to-surface conversion of NURBS-body, to use GEOMPROJEC (Projecting Geometry) as one of the means of creating markup on complex bodies and surfaces. This knowledge and skills to professionally solve and design solutions [15-18] will be useful for construction students, not only in preparation for Olympiads, but also in the future work of a designing engineer.
2. Algorithm of basket construction in AutoCAD

The construction of a woven decorative basket, see Figure 1(a), which consists of the following basic elements, see Figure 1(b): bases (1), fifteen rods (2), 14 turns of wire, spirals through the bars (3), rim (4) and braid of the rim wound spirally (5), is considered. It is believed that when a wire is twisted, a spiral is formed in the form of a broken line with rounded corners.

The diameter of the sphere \(D\) is chosen so that only in the upper section the straight segment of the wire touches the rod.

The theoretical contour of the surface of the basket wall, see Figure 1(a), is a segment of a sphere with the radius \(R\). First of all, the diameter of the basket is determined on the basis of the parametric drawing [19] of the top view, see Figure 1(c), with imposing geometric relationships (coincidence, tangency, perpendicularity, parallelism, horizontality, fixation) that can be imposed automatically, and dimensional dependencies (wire diameters \(D_1\) and rods \(S_1\), of the angle of the rods \(a_1\)), specified in the condition. Parametrization revealed the diameter of the rods 231.34 mm, the diameter of the helix for braiding the basket 242.28 mm.

Wire (3) should braid the rods in a spiral, the number of turns – 14, see Figure 1(b). The turns are located on the surface of the segment of the sphere \(\varnothing 242.28\) mm and the height of 70 mm (14 turns of 5 mm each). On this segment of the sphere, Figure 2(a), it is necessary to make a markup, on the nodes of which to form a spiral in the form of a broken line. 15 radial beams (according to the number of rods) will participate in the markup after 24° and 105 horizontal lines with an interval of 0.67 mm (the height of the turn is divided by 7.5, since in each turn of the spiral the wire approaches the marking nodes through one rod, 5:7.5=0.66666). The markup is done by the GEOMPROJEC (Projecting Geometry) command along the Z axis of the UCS. Projections are circles, circles and segments, the intersection of which will be the nodes of the grid. The 3DPLINIA team constructs a spiral on the sphere in the form of a broken line along the marking nodes. For ease of operation, the layout is set up from above, the sphere segment is removed, and the intersection snap is selected. The resulting helix will serve as a trajectory for the wire Cross section \(\varnothing 5\) mm of the SHIFT command. Figure 2(b) shows the basket braid, the angles of which are interfaced with the radius of 0.4 mm.

The bars (2), see Figure 1(b), are created by the SHIFT command of a circle \(\varnothing 5\) mm along the arc of the found radius of 115.67 mm and multiply by the MASSIVECIRCLE command (Circle array) with the number of objects 15, see Figure 2(c). At this stage, it is necessary to insert the rods into the...
wire braid of the basket and make a cut of the model to control the absence of their intersections or use the command INTERCHANGE (Interaction Test).

The braid of the rim (5), see Figure 1(b), is tightly wound to the turn with minimal clearance, except for the places where the rods are connected to the rim. In these places, the braid wraps around the rod in one turn. To build a braid of a circular rim, you need to create a fragment equal to 1/15 of the braid, and multiply it in a circle. The fragment will consist of 7 identical turns and one stretched. In order to build a braided spring, located along the arc [19], it is necessary to "curve" the wavy line and use it as a trajectory for the section of the braid of the SHIFT command.

As the helical line, the extracted outer contour \(c\) of the helicoid will serve, see Figure 3(a). To form a helicoid it is necessary to apply the SHIFT command for a radially located segment \(a\) of the length of 6.5 mm (radius of the rim + radius of the braid), the trajectory for the "shift" will be the arc \(b\) of the circle, that is 18.5º (the angle is found by an experimental method from the condition of tight abutment of the turns to each other), the angle of twist 2520º \((360º\times7)\). From the obtained helicoid-surface NURBS by the command REMOVESURFACECURVES (Remove the isolines) the outer isoline-spline is extracted \(c\), on which the SHIFT command "shifts" the circle \(A\) \(\varnothing 5\) mm, see Figure 3(b). 7 compressed turns were formed, each corresponding to an arc of 2.64º, then the stretched coil will be located on the arc 5.50º, see Figure 3(c).

The stretched coil is created on the basis of a compressed coil, the helix of which is torn at arbitrary points 3 and 4. From the spline 3-4, a block is created, with the X-axis of the UCS set by points 1-2. The block is an object that scales across axes with different coefficients. When inserting the block into the place of the stretched turn, where the spline segments are pre-inserted 1-4 and 2-3, set the scaling factor along the X axis to 3.036 \((4.65 / 2.52)\). To the block we use the command INTERSECT. After connecting the break points, for the smoothness of the spline, you need to remove 1 ... 2 of its vertices.
at the junction points. The elongated coil of the helix also "moves" the circle $\varnothing$ 5 mm by the \textit{SHIFT} command.

As segments 1-4 and 2-3 have not been changed, the turns are tightly connected to each other and can be combined by the \textit{MERGER} command, see Figure 3(d). But in order to reduce the amount of the file, the fragments of the braid are not combined, a block is created from them and multiplied by the \textit{MASSIVECIRCLE} command with the number of objects 15.

It remains to make the base of the basket (1) from the original drawing, see Figure 1(b). The \textit{ROTATE} to the contour is used as shown in the section of the initial data. Holes in the base and rim under the rods are made when assembling, by subtracting copies of rods from them. The basket is "woven", see Figure 4. File size is 16.8 MB.

3. Algorithm of soccer ball construction in AutoCAD

To build a soccer ball of outside $\varnothing$ 226 mm, consisting of three main components: chambers (1), gaskets (2) and tires (3), see Figure 5(a).

The tire (3), see Figure 5(d), consists of 12 parts - fragments of a thin-walled spherical shell 3 mm thick. The shape of the fragments is formed by arcs of 12 mutually tangent circles of equal radius uniformly located on the surface of the sphere. Ten identical parts (9) have a shaped shape, consisting of a spherical circle and two adjacent spherical triangles. Two parts (8) are circular spherical segments, on one of them a hole for the nipple $\varnothing$ 6 mm.

It is necessary to relate the construction of contiguous circles uniformly located on the surface of the sphere with a regular polyhedron, the dodecahedron [20], in which 12 faces are arranged to each other at an angle of 116.5651º. Based on this, we construct a parametric drawing of the front view, see Figure 6(a), on which geometric dependencies (coincidence, perpendicularity, horizontality, equality, fixation) and dimensional dependences (diameter of the sphere $D_1$, angle between planes of circles $a_1$, angle between the axes of circles $a_2$). From the parametric drawing we know the diameter of the contacting circles $c$ and $b$ (and all others) lying on the sphere $O \varnothing$ 226 mm. It is 118.8152 mm.

\begin{figure}
\centering
\begin{subfigure}{0.45\textwidth}
\includegraphics[width=\textwidth]{fig5a.png}
\caption{The soccer ball. Initial data.}
\end{subfigure}
\begin{subfigure}{0.45\textwidth}
\includegraphics[width=\textwidth]{fig5b.png}
\caption{Construction of tires.}
\end{subfigure}
\end{figure}

Using GEOMPROJEC (Projecting Geometry), we build the markings on the sphere, see Figure 6(b), by projecting circles $c', b' \varnothing$ 118.8152 mm, whose axes $q$ and $i$ are located at the angle 63.4349º. The projections are circles $c$ and $c''$, $b$ and $b''$, which are pairwise symmetric with respect to the center [21], as well as the faces of the dodecahedron. The remaining circles are obtained by multiplying $b$ and $b''$ by the \textit{MASSIVECIRCLE} team with the number of objects 5.
To form the fragments of the tire, see Figure 6(c), the sphere turns into a surface with the command INSTERSECTION. Use the SURFACETRIM command (Trim) on the resulting surface. From surfaces of two circular spherical segments and four spherical triangles adjacent to them, as well as from end spherical segments, NURBS surfaces are created, which are given a thickness of -3 mm. The edges of the fragments are interfaced with a radius of 0.4 mm. An opening is created in the upper segment Ø 6 mm. We finish the construction of the tire with the MASSIVECIRCLE for \( b \) and \( b'' \) with the number of objects – 5, see Figure 6(d).

The next component of the ball is the gasket (7), see Figure 5(c), it is a spiral with a step of 30 mm made of felt felt 2 mm thick, molded over the surface of the sphere with a gap between the windings 1 \( \ldots \) 2 mm. At the poles of the hole Ø 30 mm.

A sphere with a radius of 110 mm is created, around it a spiral with a radius of 110 mm, a height of 220 mm, a height of the turn of 30 mm, see Figure 7(a). Then a straight helix is constructed using the SHIFT command in a spiral for the segment \( k \), perpendicular to the axis \( i \) \[22\]. The shell is made of a sphere 2 mm thick, the helicoid is given a thickness of 2 mm. From the shell, the helicoid is subtracted by the DELAY command. The gasket is constructed, see Figure 7(b).

![Figure 7. Construction of a gasket.](image-url)

Inside the ball, see Figure 5(a), there is a chamber (1) consisting of 10 fragments of a 2 mm thick spherical shell: 8 identical petals (4) and two spherical octagons (5, 6) with a side dimension of 30 mm, see Figure 5(b). In the upper cover there is a nipple with a diameter of 5 mm with a height of 7 mm with a hole Ø 1 mm. The radius of fillet at the junction of the nipple with the camera - 1mm.

The sphere for the camera taking into account the thickness of the tire and gasket will be a radius of 108 mm. On the axis of the sphere, an octagon is built for marking \( n' \) with a side of 30 mm and a beam \( l' \), which is multiplied by the MASSIVECIRCLE command with the number of objects – 8, see Figure 8(a). The GEOMPROJEC command creates a markup on the sphere: the boundaries of 8 petals \( l \) and 2 spherical octagons \( n \).

![Figure 8. Construction of a camera.](image-url)

![Figure 9. A soccer ball in a cut.](image-url)
Using the command \textit{INTERSECT}, a surface is obtained from the sphere from which two petals and two spherical octagons are created symmetrically with respect to the center by the command \textit{SURFACETRIM}, see Figure 8(b). Then they are converted into NURBS surfaces, and they are given a thickness of -2 mm. In one octagonal overlay the nipple is constructed as a cylinder of the given dimensions, it is mated with the chamber and the hole is made by subtracting the cylinder $\varnothing \ 1 \text{mm}$. The petals are multiplied by the \textit{MASSIVECIRCLE} command and all the camera parts are collected, see Figure 8(c).

It remains to collect all three components of the ball and make a cut to verify the correct assembly, see Figure 9. The file size is 3.7 MB.

4. Conclusion
The above works convince that AutoCAD, being the main graphic package for the students of builders, allows successfully solving complex original tasks on geometric constructions. The use of parametrization simply and easily provides answers to difficult, seemingly insoluble questions. Using the \textit{GEOMPROJEC} command further diversifies the choice of capabilities when solving complex problems. Converting bodies in the surface, surfaces in the surface of NURBS, the surface of NURBS into the body builds a flexible chain of transformations in computer modeling.

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