UDC 621.9.042

SPECIAL STRATEGY OF TREATMENT OF DIFFICULTY-PROFILE CONICAL SCREW SURFACES OF SINGLE-SCREW COMPRESSORS WORKING BODIES

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The article deals with the problems arising during the shaping of complex profile tapered helical surfaces. These surfaces form the geometry of the working bodies of single-screw miniature compressors, which have great prospects for use in mobile miniature compressor plants, which is especially important for medical and space technology, robotics, oil and gas and mining industries. Due to the fact that the capabilities of existing CAD systems do not allow obtaining three-dimensional models of these surfaces, the problem of preparing a control program for a CNC machine arises, since the calculation of the tool path in CAM systems when processing complex surfaces is impossible without a three-dimensional surface model. To solve the problem, an automated programming system was developed that implements a formalized toolpath calculation in accordance with the proposed special processing strategy for conical helical surfaces. As the initial data for calculating the toolpath, the system needs information about the tool geometry and the helical surface in a parametric form, which makes it possible to abandon the construction of a three-dimensional surface model. The results of processing prototypes for the proposed strategy are given.

Key words: processing strategy; automated programming system; programming processing on CNC machines; non-profiled tool; compound-shaped tapered screw surface; single screw compressor

How to cite this article: Vasil'ev A.S., Goncharov A.A. Special Strategy of Treatment of Difficulty-profile Conical Screw Surfaces of Single-screw Compressors Working Bodies. Journal of Minig Institute. 2019. Vol. 235, p. 60-64. DOI: 10.31897/PMI.2019.1.60

Introduction. In many areas of industry, there is an increasing need for compact mobile compressor units. Such facilities are particularly relevant for the needs of medical and space technology, robotics, oil and gas and mining industries [6]. At the moment there are a large number of various designs of compressors, but single-screw compressors are the most promising from the point of view of compactness (Fig.1). As a working body in this design, a conical screw pair is used, which consists of a conical screw rotor rotating inside a conical screw holder (Fig.2). Such a construction was proposed in 1934 by the French scientist René Muano [5], the idea was implemented in 2016 by the Scottish company VERT Rotor [9].

A distinctive feature of this design is high volumetric productivity compared to other types of compressors. For example, with the same output characteristics, a single-screw compressor with a conical pair is 4-6 times more compact than a traditional twin-screw compressor. In addition, devices of this type are characterized by low levels of vibration and noise. These features determine the high potential of the single-screw design on the compressor equipment market [7].

Formulation of the problem. The main technological task in the production of a single-screw compressor is the manufacture of a miniature conical screw pair. The geometry of the helical surface of parts of a conical pair resembles the surfaces of the working bodies of gerotor pumps, widely used in industry. Distinctive features of a conic pair are varying pitch, cross-section diameter and eccentricity of the screw surface. Changes in pitch, eccentricity and diameter are related by some functional dependencies that determine the characteristics of a screw pair (volume flow, compression ratio, etc.).

The technological capabilities of most methods for the treatment of the screw surface of rotors of gerotor pumps do not allow processing conical screw surfaces due to their design features: variable pitch, eccentricity, and section diameter. Implementation of processing of this type of surfaces is possible only due to processing with a non-profiled tool on CNC machines [2].

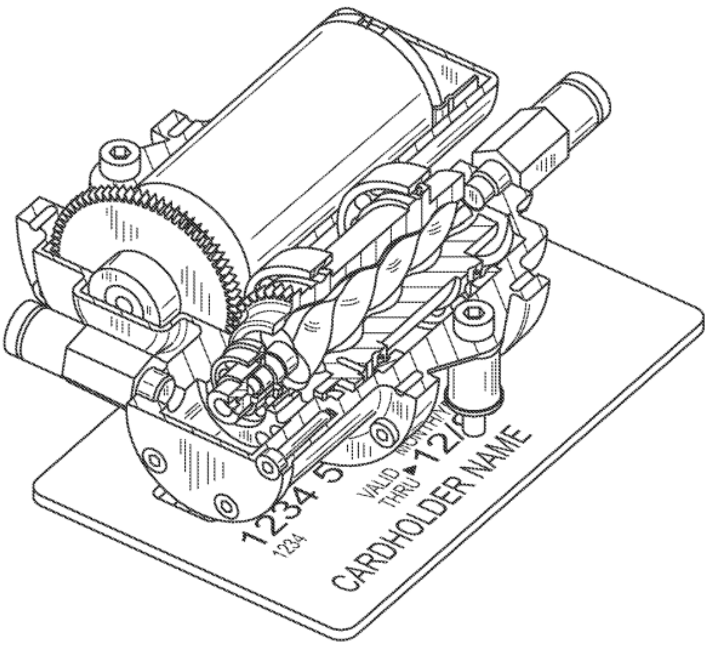

Fig.1. Miniature single screw compressor with conical screw pair

Fig.2. Conical screw pair

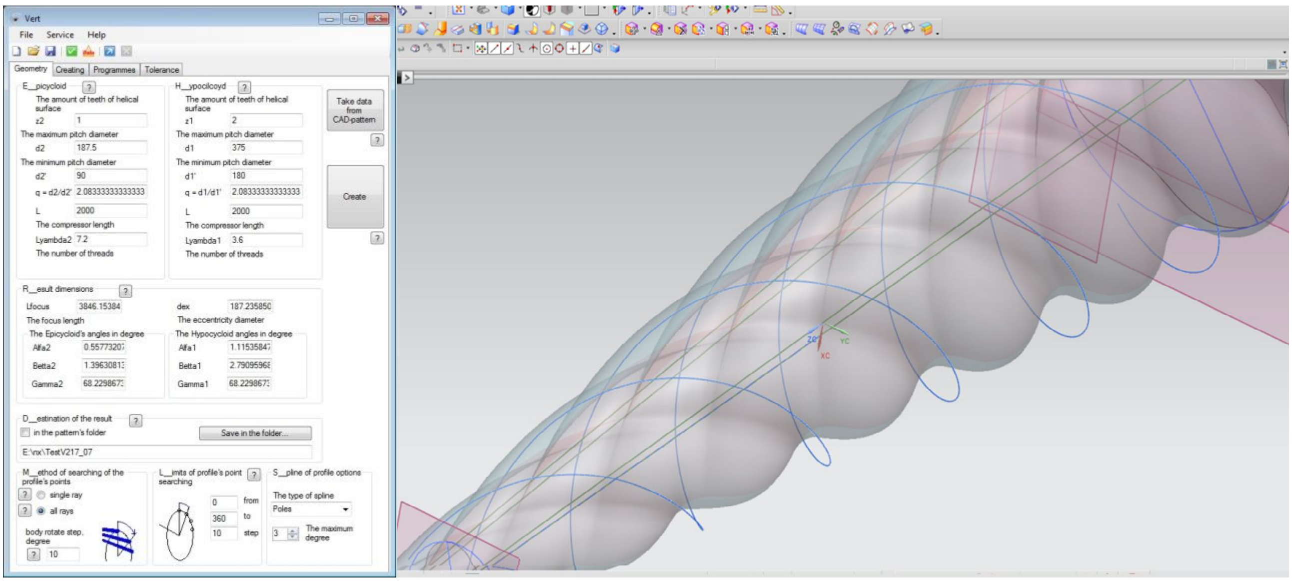

Fig.3. Specialized CAD-system for the design of conical screw pairs

Processing a complex surface on a CNC machine involves the preparation of a control program using a three-dimensional surface model. At the same time, the techno-log programmer chooses any of the standard processing strategies available in the CAM system, which often do not allow to provide the required accuracy and surface quality [4, 8]. In the case of conical helical surfaces, the creation of a virtual surface model is a very time-consuming task, which is not possible to implement in standard CAD systems. VERT Rotor, which is currently the only manufacturer of single-screw compressors, has developed a specialized CAD system (Fig.3), which allows the operator to set the required dimensions, compression ratio and tolerances. The software automatically creates a screw surface model, which is a 3D CAD model that can be sent to the CAM package for programming processing [10].

DOI: 10.31897/PMI.2019.1.60

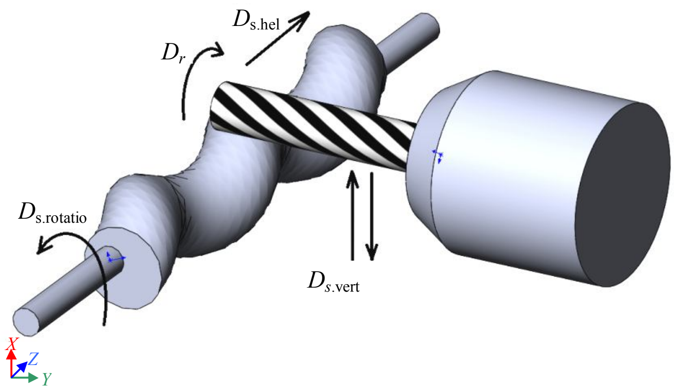

Fig.4. Screw surface treatment by special strategy

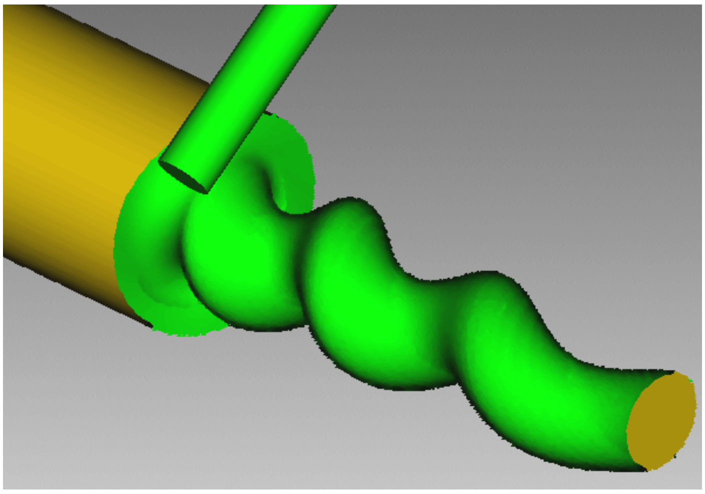

Fig.5. General view of the conical screw surface with round cross section

When developing a control program in the CAM system, the technologist has only standard strategies, using which it is not always possible to ensure the accuracy and quality of the screw surface, while maintaining sufficient processing performance.

Special strategy for machining helical surfaces. A special strategy is known for machining the screw surfaces of the rotors of screw pumps [1], which allows the machining of a screw surface with constant parameters of pitch, eccentricity and diameter of the cross section of the screw surface (Fig.4). The strategy is convenient in that it allows you to get the tool's trajectory using a formatted algorithm, which uses data about the tool geometry and the surface to be machined in a parametric form. On the basis of this algorithm, an automated programming system was created, which allows to quickly obtain the G-code of the control program for a helical surface with arbitrary parameters.

In the case of using this strategy for machining conical helical surfaces, it is necessary to add dependencies to the formalized algorithm, defining interrelations of changes in pitch, eccentricity, and section radius of the surface. For example, consider a variant of processing a conical screw surface with a circular cross section (Fig.5).

The main operating characteristic of volumetric machines is the volumetric flow, which for single-screw pumps is determined by the expression [3]:

$$Q = Shn, \tag{1}$$

where S – effective cross-sectional area of the screw pair; h – screw surface pitch; n – rotor speed.

The effective cross-sectional area of the screw pair in the considered case of circular cross section is determined as follows:

$$S = 4ed, \tag{2}$$

where e – screw surface eccentricity; d – diameter of the screw surface.

The presented dependences are valid for a single-screw pump having a screw pair with constant geometrical parameters, and are formulated from the condition of incompressibility of the pumped substance. In the case of a single-screw compressor, the geometry of the pair should provide a certain amount of compression ε, i.e. a certain degree of reduction of the working volume of the V chamber of the screw pair in the longitudinal direction:

$$\varepsilon = V_1/V_2. \tag{3}$$

In this case, the working volume is expressed through the parameters of the screw profile:

$$V = \frac{Q}{n} = 4deh. \qquad (4)$$

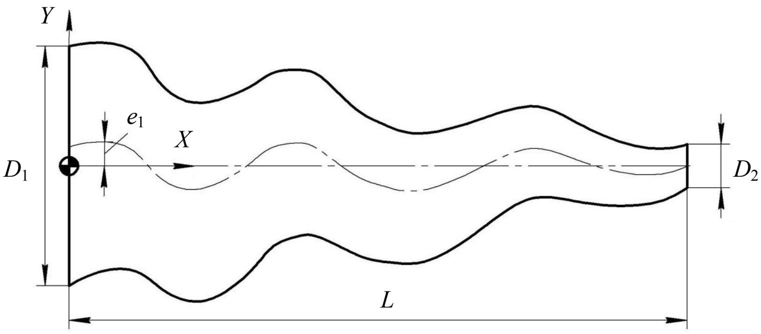

Fig.6. Parameterized sketch of a conical screw surface

Using the given dependencies, as well as considering the sketch of a helical surface (Fig.6), we can write expressions that determine the values of the geometrical characteristics of the helical surface in a certain cross section, characterized by the value of X. Thus, it was obtained the following equations for the geometrical parameters of the helical surface:

$$\begin{cases} D(x) = D_2 + \dfrac{D_1 - D_2}{L}; \\ e = k_{\text{в}} D(x); \\ h = \dfrac{V(x)}{4D(x)e}. \end{cases} \qquad (5)$$

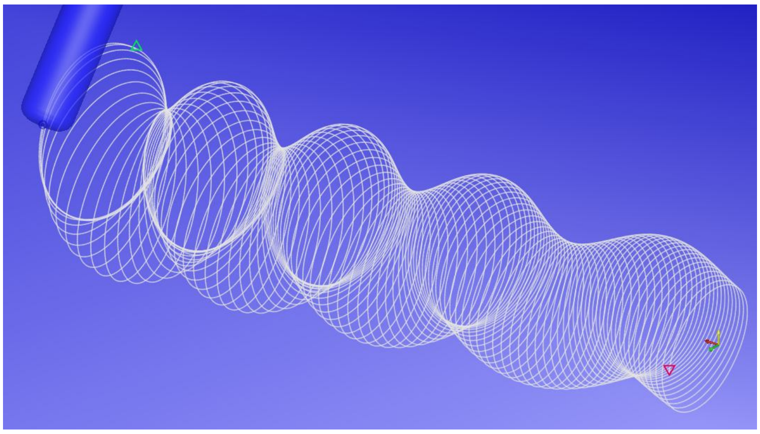

Fig.7. Tool path

Experimental confirmation. Integrating the functional values of the geometric parameters of the surface into the existing automated system for calculating the tool path, we obtain a control program for processing a conical helical surface, which is a text file with a G-code. The resulting trajectory of the instrument is shown in Fig.7.

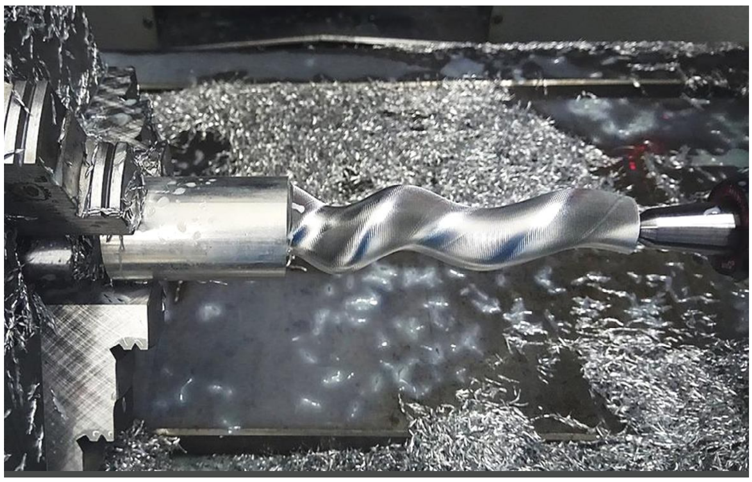

Fig.8. Screw surface machined according to the proposed strategy

The test machining of the screw surface was carried out on a CNC vertical milling machine equipped with a rotary table of the HAAS MINI Mill 2 model. A screwed conical surface with a maximum cross-section diameter of 10 mm, a basic pitch of 48 mm, a base eccentricity of 3.4 mm, a surface length of 100 mm was machined, screw compression ratio ε = 1 (without compression). Preparation material – alloy D16T. Cutting tool - end carbide cutter for machining aluminum alloys with a diameter of 6 mm. The result of the test processing is shown in Fig.8.

In addition, a number of prototypes of the screw surface were processed with various combinations of geometrical parameters, involving different degrees of compression, with different ratios of pitch and eccentricity (Fig.9). The experiments confirmed the efficiency of the proposed processing strategy of a screw conical surface, and also showed the possibility of achieving high surface quality while maintaining high processing performance.

a

b

Fig.9. Examples of machined surfaces: *a* – geometry with a high degree of compression, polypropylene; *b* – geometry with an oval cross section, D16T

Outputs. As a result of the research, a unique processing strategy for tapered helical surfaces was developed, which was integrated into the automated programming system of the control program for the CNC machine. The system allows, based on the formatted algorithm, to calculate the tool movement path, relying not on the three-dimensional surface model, but on its parametric description, which allows not to perform time-consuming modeling of these surfaces in CAD systems. Experimental processing of a number of surfaces with different parameters showed the effectiveness of using the proposed processing strategy. It should be noted that the proposed strategy allows the shaping of these complex profile surfaces using standard non-profiled tools on the available four-axis equipment, does not require the use of five-axis CNC machines or any other specialized equipment and tools.

In addition, it was found that modeling of the surfaces under consideration using standard CAD systems is almost impossible, which in turn causes a number of problems associated with the metrological evaluation of the accuracy of data processing of helical surfaces.

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The paper was received on 23 May, 2018.
The paper was accepted for publication on 13 June, 2018.