

THE PROBLEMS OF THE DESIGN AND ENGINEERING OF VARIABLE-PITCH CONE WORMS

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Abstract: Variable-pitch cone worms, used in extruding press plasticizing systems, whose geometry varies on the length of the screw, are carried out by trial and error method. Therefore, prior to the treatment of such worms is needed to study their geometry because of the possibility of assembling in the plasticizing system.

A special program, which is based on technology for the machining of worms with finger type cutter, it allows to identify the cutter offsets Δy , due to the straight sides of the outline of the axial profiles of worms and set clearances between the convolutions of mating worms at the design stage of worms.

Presents an analysis of a sample of the plasticizing unit, using an application developed to support the design of twin screw extruders.

Key words: cone worm, variable pitch, the plasticizing system of plastic extruding presses.

1. INTRODUCTION

Plastics find wide application in various field of the economy. The production and consumption of plastics in the world have been continually increasing for several dozen years. The dynamic of this increase is by an order of magnitude greater than that of other constructional materials. As the processing of plastics develops, the demand for machinery for this process increases. Of the plastics processing methods, extrusion and its variants have definitely the largest share in production [12]. The quality of manufactured product, as well as the efficiency of the manufacturing process, depend largely on the geometry and execution accuracy of the plasticizing system. Extruding presses use various plasticizing system [12], but a system composed of two counterrotating untightly meshing worms in the most efficient.

Variable-pitch cone worms, used in extruders for transferring and plasticizing the plastic, are characterized by variable geometry, which makes its technology and measurement very difficult. The worm has several zones (supply, compression, pre-

heating, degassing, metering) which have different geometry, depending on the function that they perform. From the point of view of design and engineering, each of these zone can be considered as a separate worm. These are multi-convolution worms with either a constant or variable pitch. A characteristic feature of the cone worm is the variability of all geometrical parameters along its length, with the pitch for a given convolution at the beginning and at the end being different (Fig. 1), but different pitches for both sides of the same convolution are also possible, which in practice makes their execution and accuracy checking difficult. These worms are cut with a finger-type cutter (conical, with the axial profile perpendicular to its action face) on a special numerically controlled milling machine [1, 2, 7, 13, 14]. It is also assumed that the worm's axial profile has to be rectilinear [3, 5, 7, 13, 14].

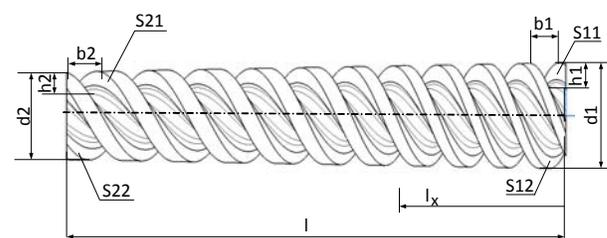


Fig.1. A cone worm with a variable pitch

The basic problem with the double-worm arrangements to achieve the proper values of the inter-convolute clearance, which should be constant over the entire height of meshing convolutes in the axial section and over the entire worm length.

The axial profile obtained from the machining of the worm with a grinding wheel or cutter with a rectilinear profile in the axial section of the tool's action face will be different from rectilinear. This will therefore be an arbitrary profile, being dependent also

on the relative tool to worm position in the machining process.

Considering the variability of all the geometric parameters (pitch, outer and inner diameters) of the worm along its length, this profile is variable over the worm length and is not verified in practice. The inter-convolute clearance, on the other hand, is verified in several ways. The measurement is performed on a special stand and consists in assembling (fixing in the centres) an arrangement of the pair of worms made, which will correspond to the arrangement of these worms in the extruder. The most straightforward method is to determine the inter-convolute error by visual observation of the gap between the convolutions (a white piece of paper is put under the worms). The inter-convolute clearance (between non-planar worm convolution surfaces) is also determined using a feeler gauge (with flat filer blades). The inter-convolute clearance determination method by measuring the magnitude of the rotation angle of one of the worms with the other being fixed is also used. The first two methods only allow the evenness of the clearance to be estimated approximately. By contrast, the third method enables the determination of the magnitude of minimum clearance (which will occur in one location on the worm length), rather than the distribution of clearances over the length of the mating worms.

In the case of worms for which the technological parameters (a fixed cutter, a fixed specialized machine tool, known machine tool settings) of the tools have been established by trial and error, determining the inter-convolute clearance does not cause any major problem. However, should a change or modification to the existing technology (e.g. changing the tool diameter or using a multi-purpose CNC machine tool) be attempted or a new worm be required to be made, determination of the inter-convolute clearance by trial and error would already be too costly. And considering the fact that new types of plastics are consistently being introduced to plastics processing, the need for using worms of ever varying geometry, also in plastics extruders, should be taken into account.

Also, the possibility of machining variable-pitch cone worms on multi-purpose CNC machine tools, as well as the likelihood of using also cylindrical finger-type cutters for their machining should be taken into consideration [12].

Therefore, for the analytical determination of the magnitudes and distribution of inter-convolute clearances, a special software application has been developed, which is based on the worm machining technology and allows the clearances to be determined as early as at the worm design stage.

2. ANALYSIS OF THE CONE WORM MACHINING PROCESS

2.1 The application for the analysis of the double-worm system

To determine analytically the inter-convolute clearances and their distribution, the mating worm surfaces need to be described. The worm surface (convolution flank) depends on the geometrical parameters of the tool, its positioning relative to the worm being cut, and the kinematics of machining; therefore, the analysis of the worm machining process should be made. During machining of a worm using a finger-type cone cutter with a rectilinear profile in the axial section of the action surface, the axis of the cutter is positioned perpendicularly to the worm cut bottom and is offset from the worm axis by a specific value of Δy variable along the worm axis (length) (Fig. 2).

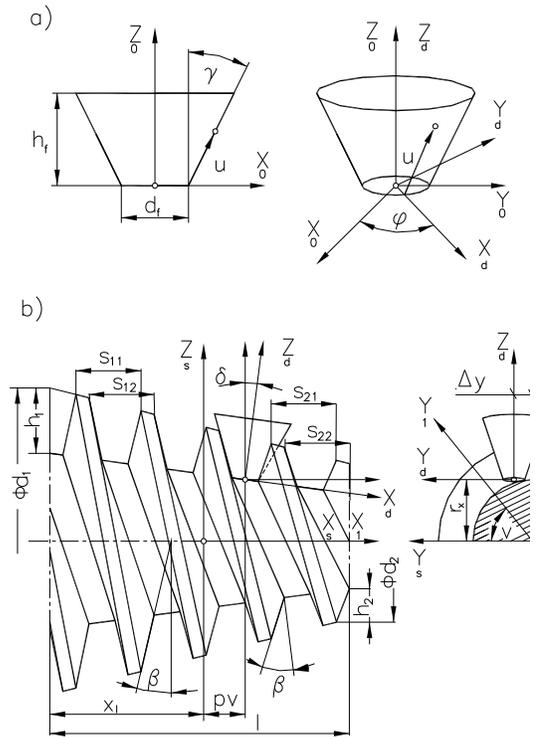


Fig. 2. Schematic diagram of worm surface generation: a) a finger-type shank cutter; b) cutter positioning and worm machining

From the condition of ensuring the minimum worm axial profile deviation from the straight line, the optimal values of the parameter Δy are determined [7, 9].

$$\Delta y = f\left(\gamma_f, d_f, s_{11}, s_{12}, s_{21}, s_{22}, b_1, b_2, l, x_l, k, h_1, h_2, d_1, d_2\right) \quad (1)$$

where: γ_f - cutter axial profile angle; d_f - minor cutter diameter; s_{11}, s_{12}, s_{21} and s_{22} – pitches on the left-hand and right-hand cut sides, at the beginning and end of the worm (zone); l – worm (zone) length; x_1 – position of the examined profile on the worm (zone) length; k – multiplicity of the examined profile (left-hand or right-hand); h_1 and h_2 – axial profile heights at the beginning and end of the worm (zone); d_1 and d_2 – outer diameters at the beginning and end of the worm (zone).

The Δy parameter is important for setting the machine tool for machining the worm, as well as for describing the surface of the mating worms [1, 4, 7, 8, 9].

The equation of the cutter action surface family in the worm system, \bar{r}_s , and the envelope condition, f_1 , jointly describe the worm surfaces, which can be represented by the following general relationship:

$$\bar{r}_s = \bar{r}_s(u_f, \varphi_d, v) \quad (2)$$

$$f_1(u_f, \varphi_d, v) = 0 \quad (3)$$

where: u_f - parameter of point position on the straight line generating the cutter axial profile;

φ_d - parameter of cutter action surface,

v - parameter of relative cutter and worm motion in the machining process;

To the above equations (2, 3), the worm axial profile condition is added

$$f_2 = y = 0$$

$$f_2(u_f, \varphi_d, v) = 0 \quad (4)$$

whereby a system of equations describing the worm axial profile is obtained.

For a preset value of the parameter u_f , respective values of the parameters f_1 and f_2 are determined from the system of equations φ_d and v . After substituting the values of these three parameters to the vectorial equation (2), the coordinates of the worm axial profile point are obtained. The computation cycle is repeated for the successive values of the parameter u_f . This makes it possible to determine the worm axial profile in the position on the worm length as defined by the value of the parameter x_1 .

For determining the inter-convolution clearance, a method was employed, whereby the system of worms is cut by the set of planes parallel to the worms' axes. In each cutting plane, worm convolution profiles were obtained in a discrete form of sets of points. In any arbitrary cutting plane, the profile of the one side of the first worm's convolution and the corresponding (mating) profile of the second worm are two curves

obtained in a discrete form of sets of points. These curves are substituted (by the approximation method) with the sets of points projecting into (equally spaced on the axis of abscissae) nodal points of the ordinate grid introduced in the respective cutting plane [1]. As a result, the ordinates of so defined convolute section curves can be compared with each other and the clearances between convolutions in a given cutting plane can be determined. Taking successive cutting planes into consideration, the distribution of clearances in the system of two counterrotating non-tightly meshing worms can be determined.

This has resulted in the development of a software application aiding the design (engineering) of the system composed of two cone worms cut with a conical finger-type cutter. The application includes modules covering the successive stages of analysis of a double-worm system. The first module is used for determination of the optimal values of cutter offsets Δy , on account of the rectilinear profile of worm cut flanks, for right-hand and left-hand convolution worms. The next module, using the results yielded by the first module, calculates the specific angle of cut "flare" with the cutter in the frontal section (engineering parameter), or the angle of tool rotation around the worm axis for the preset cut width in the axial section. Then, the system composed of two mating worms is formed and the worm sections made by a common cutting plane and the inter-convolution clearances are determined – Figure 3. The software program was developed in the Delphi language as a RAD (Rapid Application Development) application to run under the Windows environment. At the same time, a code in the AutoCAD AutoLisp language is generated for generating a more detailed drawing of the inter-convolution clearance distribution (the graphics in Delphi using the TChart component is for illustrative purposes only – Fig. 3).

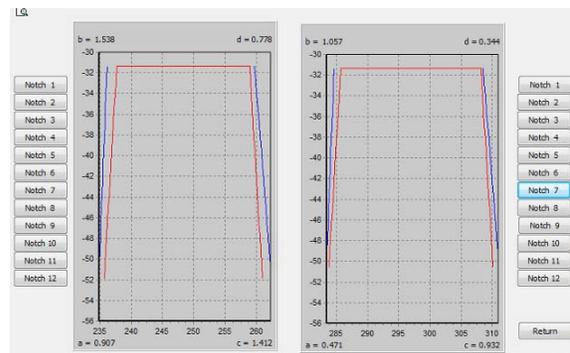


Fig. 3. Distribution of clearances in the axial plane in arbitrarily selected cuts of a system composed of two cone worms of parameters as given below

Cone worms can also be cut with cylindrical finger-type cutters [4, 6], and the developed

computation program allows also for this method of machining, except that in that case the position of the tool is different and the cut bottom is machined separately. These worms can be cut not only on special machine tools [15, 16], but also on modern universal multi-axial multi-task CNC machine tools [10, 11, 17]. Special machine tools for worms [15, 16] allow cylindrical worms to be machined using special heads by the whirling method, which is an accurate and efficient method. Due to the limited range of diameters, the whirling method of machining is mostly used for cutting threads.

2.2 Analysis of the system of two cone worms

Based on the worm documentation and working drawings obtained from a production plant, the geometrical analysis of a system composed of two cone worms was made.

The parameters of the system of two cone worms (a right-hand and a left-hand one) under consideration were as follows:

worm pitch at the zone beginning, $s_{11} = 129\text{mm}$;

worm pitch at the zone end, $s_{22} = 168\text{mm}$;

cut width at the zone beginning, $b_1 = 27.5\text{mm}$;

cut width at the zone end, $b_2 = 32.5\text{mm}$;

zone length, $l = 710\text{mm}$;

outer worm diameter at the zone beginning, $d_1 = 110.81\text{mm}$;

outer worm diameter at the zone end, $d_2 = 81.5\text{mm}$;

axial profile height at the zone beginning, $h_1 = 23.4\text{mm}$;

axial profile height at the zone end, $h_2 = 19\text{mm}$;

worm multiplicity, $z = 3$.

Cutter parameters:

cutter diameter, $d_f = 14\text{mm}$

cutter inclination angle for the change in cut profile angle, $\vartheta = 10^\circ$.

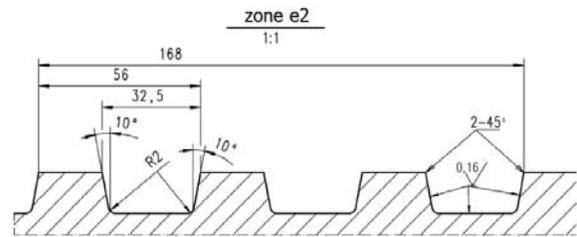
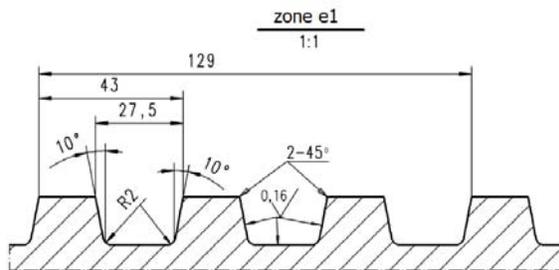


Fig. 4. Part of the section of the worm analyzed

The analysis of the system under consideration was made using the developed double-worm system design aiding program with preset initial parameters – Figure 4. The parameters of relative worms and cutter positioning in the machining process were computed due to the rectilinear axial profile of the cut flans (Fig. 5). As a result of the computation, it is theoretically possible to obtain axial profile deviations from the straight line with an accuracy not exceeding 0.03 [mm].

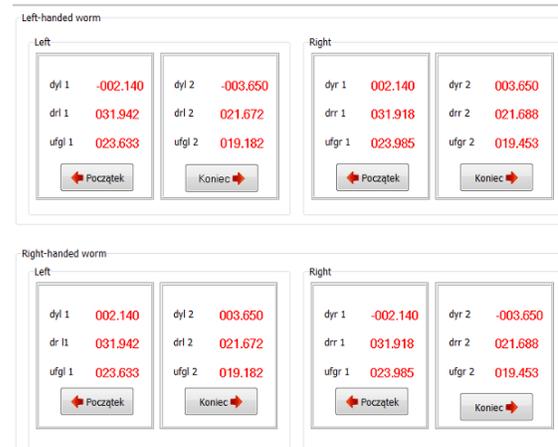
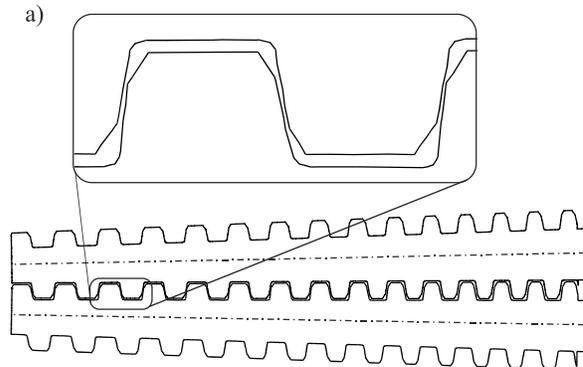


Fig. 5. Geometric data with the technological parameters of relative worms and cutter setting during machining, as computer with the double-worm systems design aiding program



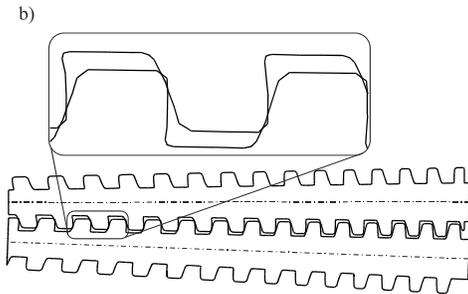


Fig. 6. Sections of a system of a right-hand convolution and a left-hand convolution worms with the following parameters: $s_{11} = 129\text{mm}$; $s_{22} = 168\text{mm}$; $b_1 = 27,5\text{mm}$; $b_2 = 32.5\text{mm}$; $l = 710\text{mm}$; $d_1 = 110.81\text{mm}$; $d_2 = 81,5\text{mm}$; $h_1 = 23.4\text{mm}$; $h_2 = 19\text{mm}$; $z = 3$, and a profile tooth space angle of 10° a) by the axial plane (passing through the worm axes), b) by the plane parallel to the worm axis and offset from it by 10mm

The plasticizing system is composed of two cone worms (a right-hand convolution and a left-hand convolution one) arranged in a cylinder. The worms are set in such a manner that the radial clearance between them and the clearance between the worms and the inner cylinder surface are 2 mm. The inter-convolution clearance in the axial profile should be constant and evenly distributed along the profile height and the worm length. For comparison, the system was modelled in the Catia program based on the previously determined parameters (Fig. 6).

As can be seen in Figure 6a, there is a clearance (varying along the worm length) between the convolutions of the mating worms, but after defining the profiles in the section made by the plane parallel to axial plane and offset from it by e.g. 10mm, the clearances take on a wedge shape, and in some locations the profiles intersect – Figure 6b.

This implies that such a system cannot be assembled without the change to the geometrical parameters of the worms. Only the correction to the cut width, bevelling of the profile vertices or the change to the profile angle will provide such possibility. It should be noted that the pitch is variable over the worm length; it different at the beginning and at end of the worm, as indicated by the engineering drawing. On the other hand, the variable worm cut width indicates also that there is a difference in pitch between the left and the right sides of the same convolution's profile. Therefore, prior to the machining of this type of worm, a detailed analysis of the entire system should be made, with the examination of clearances between convolutions, not only in the axial section.

After making specific worm convolution vertex bevelling corrections, the $2-45^\circ$ bevel was substituted with a bevel of $3 \times 4\text{mm}$ (such an operation is used in practice), the system was modelled again and the clearances between the convolutions of the mating

worms were analyzed (Fig. 7), whereby the desired result was obtained.

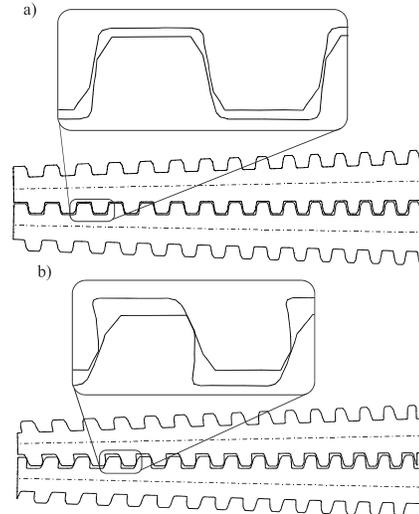


Fig. 7. Sections of a system of a right-hand convolution and a left-hand convolution worms with changed parameters: a) by the axial plane (passing through the worm axes); b) by the plane parallel to the worm axis and offset from it by 10mm

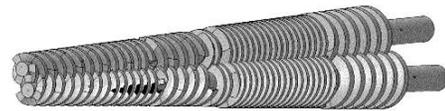


Fig. 8. The model of the system of a right-hand convolution and a left-hand convolution worms (the entire system with all zones) designed in the Catia system

Based the performed analysis it is possible to ascertain, without the time-consuming and costly making of the worms, that the plasticizing system under consideration can be assembled after making specific corrections, but the clearances between convolutions will be unevenly distributed over the length of the mating worms. This might be due to the variability of the worm pitches.

There is no simple relationship between the magnitude and distribution of inter-convolution clearances and the geometrical and engineering parameters of worms. Even the measurement of the worm axial profile will not guarantee that the interference (intersection) of the mating worm profiles will not occur at all (and the worms will be able to be assembled), if the axial profile turns out to be incorrect. So, this is a very difficult issue, and the proposed analysis of the two-worm system could help resolve these problems.

3. CONCLUSIONS

Problems related to the technology of variable-pitch cone worms used in plastics processing (in extrusion

presses) are still very difficult. It is assumed that mating (counterrotating untightly meshing) worms have a definite clearance which is uniformly distributed (over the profile height and worm length) [13]. As a consequence, such worms are made on special numerically controlled milling machines furnished with special software by their manufacturers.

With the incorrect selection of the geometric worm parameters and engineering parameters (defining the positioning of the tool and the machined worm relative to each other during machining), mating worm profile intersection phenomena will occur, which means in practice that the system will not be able to be assembled. Therefore, the elimination of this occurrence at the system's design stage would be very advantageous, considering the fact that the cost of making such a system is very high.

Only the appropriate analysis of the magnitude and distribution of inter-convolution clearances does enable the proper machining of the worms and will assure the required accuracy of their execution. A basis for the analysis is the determination of the surfaces of the mating worms, while considering their technology.

In the design of this type of system, errors will result if the following geometrical worm parameters are incorrectly designed: pitch, cur width and convolution height. This is due to the fact that the outer diameter of one worm and the inner diameter of the other worm, that is the diameters of worms with different lead angles, mate with each other. Considering the small worm diameters and the very large pitches, this is a crucial problem, all the more so because smaller-diameter worms have a larger pitch. So, the analysis of clearances in a system, as made theoretically, enables also the optimization of the geometrical parameters of mating worms.

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