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THE TECHNOLOGY OF VARIABLE-PITCH CONE WORMS IN PLASTIC EXTRUDING PRESSES

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The article describes the basics of the technology and metrology of variable-pitch cone worms that are used in plastic extruding presses. Two worms operate in the plasticizing system of an extruder. It is assumed that the axial profile of a worm should be rectilinear, and the clearance between the threads of mating worms in the axial section should be constant along the worm length and the thread height. The article focuses on the technology and measurements of worms and considers the potential for the development of this technology.

Key words: presse, extruding presses, polymer material, cone worm, variable pitch

INTRODUCTION

The process of extrusion of polymer material takes place in the plasticizing system of an extruding press. The material in the form of granulate or powder fed to the plasticizing system is transferred, heated and compressed in order to change its physical state into a plastic state and then it is mixed and degassed to homogenize its composition and physical properties. The plasticizing system is composed of a cylinder with worms, cylinder heating-cooling elements and a worm temperature equalizing system. The widest applied in the processes of manufacturing polymer materials have been double-screw indirect extruding presses and direct extruding presses with untightly meshing screws. The development of double-worm indirect extruding presses is associated with the increase in the importance of the technology of processing non-softened PVC in the form of a dry mixture, which is characterized by low thermal stability [1].

Materials to be used for the fabrication of worms and cylinders should exhibit the following properties: high abrasion resistance and resistance to mechanical loads caused by the material pressure in the cylinder, which exceeds the value of 60 - 80 MPa during the extruder start-up (the maximum torsional stresses of the screw core), no tendency to adhesion between the screw internal surface and the screw thread crests, high fatigue strength and corrosion resistance at high temperatures and pressures.

Worms and cylinders are made in general from nitriding constructional steel or from hardened steel 40HM [2-4]. It is recommended to use nitriding steel 38HMJ (41CrAlMo7 acc. to EN) or 33H3MF (31CrMoV9, 33CrMoV12-9, 40CrMoV13-9 acc. to EN) according to standard PN-89/H-84030/03. The working surfaces of the worms and the cylinder should be nitrided to an effective nitrided layer thickness of g_e 600 HV5 0,4 ± 1 mm acc. to PN-82/H-04550, while the hardness of the nitrided layer should be 900 ± 30 HV. The 40H2MF toughening steel complying to standard PN-89/H-84030/04 is also used.

The cylinder inner surface should a hardness not higher than 57 HRC. Classic (nitrided) cylinders are more and more often replaced with bimetallic cylinders, where the cylinder inner surface is lined with abrasion- and corrosion-resistant alloys (based on Ni, Cr, Co, Fe, W, V). Coating of the working surfaces of bimetallic cylinders is made by the centrifugal pouring method. The coating is done in a furnace at a temperature of up to 1200 ºC with a layer thickness of 0,7 – 1,5 mm, at a bore execution accuracy of H7 (surface roughness, Ra = 0,8 μm). These cylinders are distinguished by an operational life much (4 - 6 times) longer compared to nitrided cylinders.

In order to increase their operational life, the working surfaces of cylinders, and especially threads, are coated with alloys resistant to abrasion and corrosion [5-8]. Metal coats are applied onto worm working surfaces by electric or plasma weld cladding or by a spraying method. The most commonly used components of applied coats are iron, cobalt, nickel and copper. In the case of processing polymer plastics of increased corrosion aggressiveness, cobalt and nickel alloys are used, while tungsten carbides being used to increase the hardness. In order to further toughen its working surface, a worm can be subjected to the nitriding process or coated with technical chromium.

Also molybdenum coated worms are offered, in which thread crests are coated with a layer of a molybdenum-based alloy. In spite of not being hard (having only ~500 HV), the molybdenum layer, when mating

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with a nitrided cylinder, provides very good sliding properties and optimal abrasion resistance [9].

For example, ELKREM Sp. z o.o. of Toruń (Poland) manufactures nitrided, weld clad (stellited) and hardened worms, as well as nitrided bimetallic worms of a layer thickness from 1 mm to 2,5 mm. The following bimetallic composites are used: Fe/Cr-based with a hardness of 59 - 64 HRC; Ni/Cr- and Ni/Co-based with a hardness of 55 - 67 HRC - where increased corrosion aggressiveness occurs; and Ni/Cr- and Ni/Co-based with an addition of tungsten carbides - in the case of abrasive wear [10].

For processing plastics and rubbers with admixtures of strongly abrasive materials (e.g. rubbers filled with glass fibre, mineral fillers, fire retardants, chalk), mixtures of plastics, regulators, recycling agents and other strongly abrasive materials, a C/Cr/Co/W- or Ni/Si/Cr/B/W-based layer of a thickness of up to 2,5 mm is weld clad. Due to a high content of fine particles of sintered carbides of a hardness of approx. 2 400 HV, the applied layer has high wear resistance [11].

The company Pol-Serwis Majcher Plastic Processing Machines (Poland) offers worms and cylinders made of the 38CrMoAlA nitriding material or the 41CrAlMo7 material, on which a bimetallic layer is applied [12].

A trend towards using worms and cylinders with applied coats, abrasion- and corrosion-resistant components based on Ni, Cr, Co, Fe, Cu, W, V can be observed. Thanks to applying this technology, the operational life of plasticizing systems is increased compared to nitrided worms and cylinders.

THE PROBLEMS OF THE METROLOGY AND TECHNOLOGY OF VARIABLE-PITCH CONE WORMS

The worm technology

A worm is composed of several sections [4] with different geometric parameters, which, in respect of machining technology, can be regarded as separate worms. Worms intended for extruding presses are machined on special CNC machine tools, while for cutting cone worms, sintered carbide finger-type conical milling cutters of a small cutter diameter of 14 mm and a profile angle of 10 º are used, which are custom-made (Figure1). The machining parameters are as follows: V_c = 17 m/min, f_z = 0,12 mm/rev, a_p = 20 mm, a_e = 1 mm.

A measurement of the roughness of surfaces machined by peripheral climb milling method using a four-blade cutter with the machining parameters as above was made. The milled material was nitriding steel 38HMJ (identical to the one used for the worms). In this case (with typical milling of geometrically simple surfaces), a surface roughness of approx. 0,006 mm was obtained. Hence one can infer the conclusion that heavy tool operation conditions in milling worms are the cause of occurring errors that are unavoidable with this type of tools.

In preliminary tests carried out, a 20 mm-diameter finger-type cutter, type R215.3I-20030-BC38H, manu-

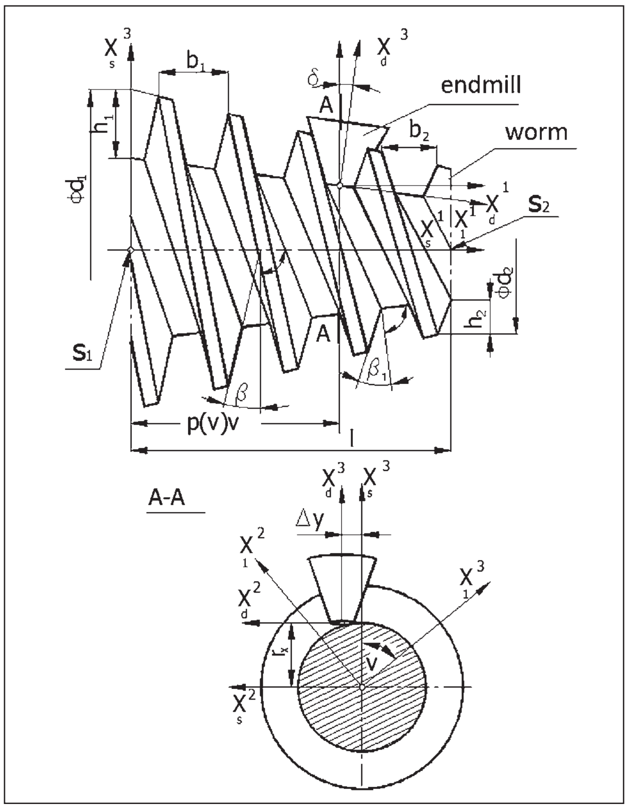

Figure 1 Relative positioning of the tool and the worm in the machining process.

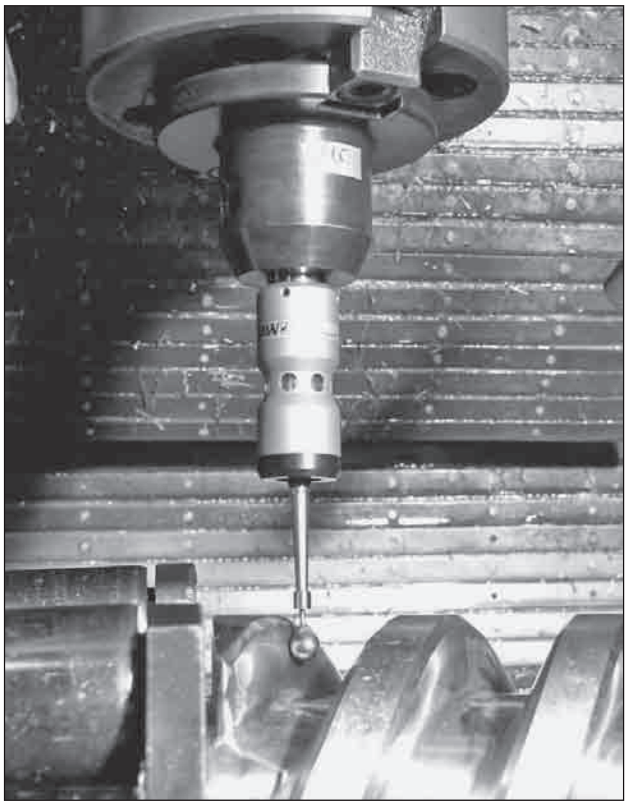
Figure 2 Measurement of the worm axial profile using a JCP1 RENISHAW probe

factured by SANDVIK Coromant, was used, with the following machining parameters: V_c = 70 m/min, f_z = 0,025 mm/rev, z = 16, a_p = 25 mm, a_e = 0,3 mm, blade life 80 min, the climb milling method. An almost 4-times increase in machining performance and an Ra surface roughness of approx. 0,4 µm were achieved. An attempt was also made to use finger-type cylindrical cutters for machining variable-pitch conical worms by milling on an Integrex universal multi-purpose CNC machine tool manufactured by MAZAK [13]. To increase the machining performance, the worms should be rough machined with a disc-type mill of a large diameter and a large number of blades.

Worm profile measurement

The cylindrical worm axial profile measurement methods are not applicable to variable-pitch cone worms. Therefore, the measurement of the worm axial profile was done directly on the machine tool making that worm, i.e. a special numerically controlled milling machine, by mounting, in place of the tool, a special Renishaw JCP1-type measuring probe of a measuring accuracy of up to 0,001 mm (Figure 2). The measurements made (Figure 3) show consistence in axial profile shape between the the measured left- and right-hand cut sides and those calculated theoretically.

However, the deviation values resulting from the measurement are virtually by an order of magnitude greater than the ones resulting from computation. There occur also profile distortions (of up to 0,06 mm) resulting from high surface roughness, which considerably exceed the theoretical profile deviation from the straight line (of the order of 0,001 mm).

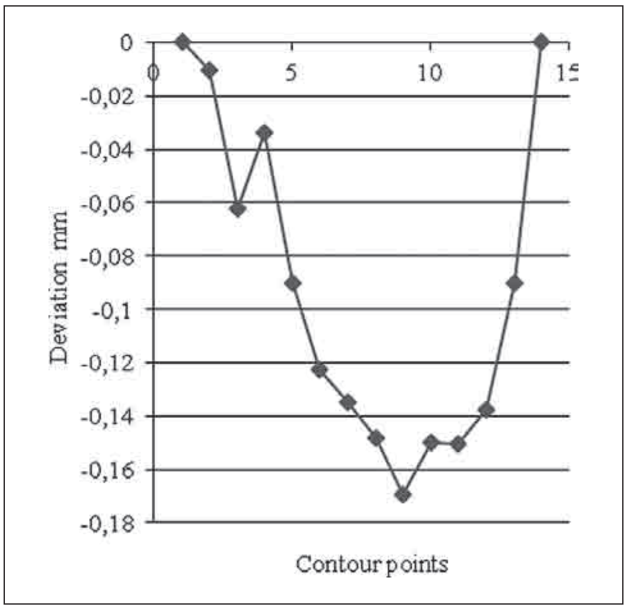

Figure 3 Example deviations of the left-hand axial profile side of a cone worm (with the following parameters: cutter diameter, d_f = 14 mm, cutter profile angle γ_f=10 °; pitch of worm 1, S_1 = 168 mm, pitch of worm 2 S_2 = 168 mm, number of threads z = 3, section length l = 710 mm, outer diameter 1 d_1 = 111,92 mm, outer diameter 2 d_2 = 81,6 mm, thread height 1 h_1 = 23,62 mm, thread height 2 h_2 = 19,05 mm, cut width 1 b_1 = 30 mm, cut width 2 b_2 = 30 mm, right-hand) from the straight line for the measurement cross-section position of x_l = 531 mm

Another method for verifying the accuracy of a worm may be by checking the face profile with a special template (Figure 4), which, considering the clearance value and the permissible profile tolerance, might prove a sufficiently accurate and very convenient (easy to implement) method. Checking the worm profile with a template by observing the light gap between the examined profile and the template profile allows the profile to be verified with an accuracy of up to 0,01 mm.

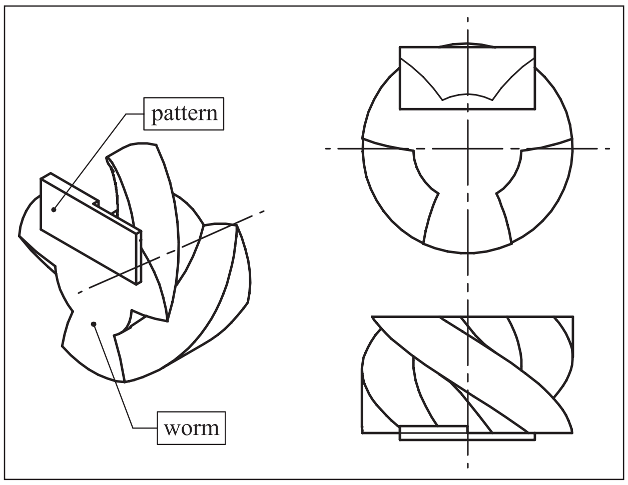

Figure 4 The principle of worm face profile measurement with a template

In the case of checking the face profile with a template, the reference worm profile in the face cross-section is cut out in the template for one profile side, while for the other side only the profile line is drawn (engraved) on the template (Figure 5). The template must be made of a transparent material. It has the datum on one profile side and in the worm cut bottom and abuts the worm face. The other one, drawn on the worm profile side template, may also be plotted in the form of lines limiting the maximum permissible profile deviations.

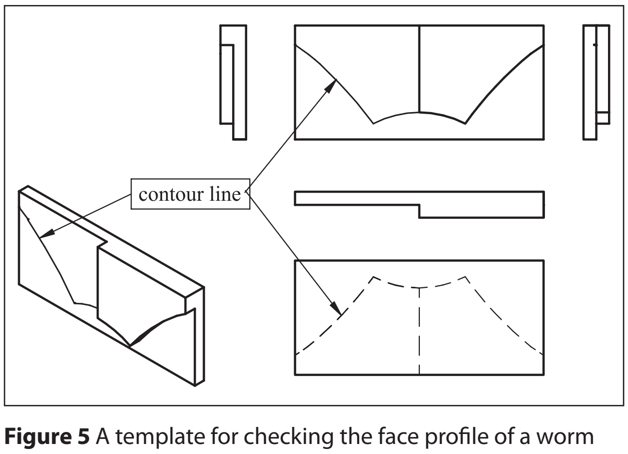

Figure 5 A template for checking the face profile of a worm

Making only one side of the worm cut face profile on the template is due to the fact that the template must rest on the edge of the worm face profile rather than on the thread flank (at the distance from the worm face being equal to the template thickness, which results from the inclination of the worm thread helix). For a left-hand and a right-hand worms, two symmetrical templates must be made.

Determination of the clearance between the threads of worms

The clearance is measured using clearance gauge by estimating the light gap between the mating surfaces, or through the magnitude of the angle or rotation of one of the screws with the other being stationary. Only the minimum clearance can be determined this way.

It is assumed that the worm profile in the axial section is to be rectilinear, whereas the clearance in the axial section between the threads of meting worms should be constant (of approx. 2 mm) at the profile height and over the entire worm length. In practice, in spite of these conditions being satisfied, it might turn out that in an non-axial section the profiles of mating worms intersect. To eliminate such cases, an analysis of

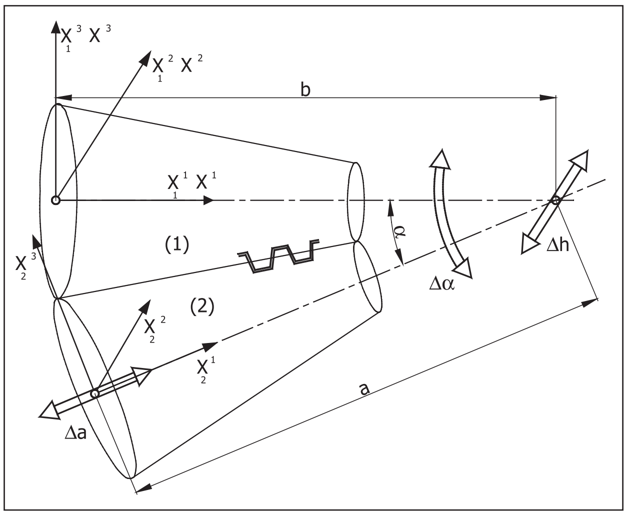

Figure 6 A system of two variable-pitch cone worms

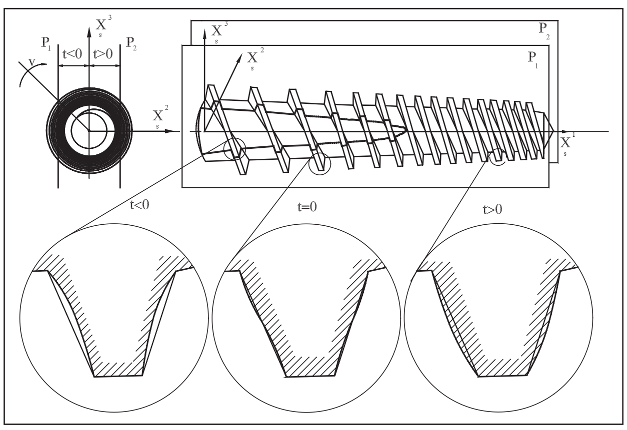

Figure 7 Principle of determination of the inter-thread clearance of mating worms

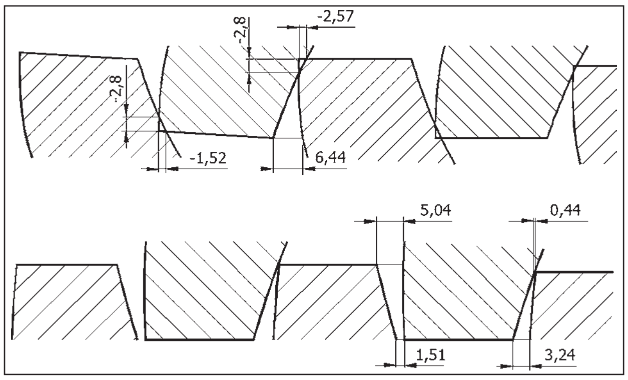

Figure 8 An intersection of a system of two worms at the beginning (the upper drawing) and at the end (the lower drawing) of the section by a common cutting plane t = 10 mm (with the following parameters: cutter diameter d_f = 14 mm, cutter profile angle γ_f = 10 °, pitch of worm 1 S_1 = 180 mm, pitch of worm 2 S_2 = 144 mm, number of threads z = 3, section length l = 675 mm, outer diameter 1 d_1 = 90,5 mm, outer diameter 2 d_2 = 115,408 mm, thread height 1 h_1 = 22 mm, thread height 2 h_2 = 24,499 mm, cut width 1 b_1 = 35,2 mm, cut width 2 b_2 = 29,7 mm, right-hand)

the distribution of clearances must be made at the stage of designing the assembly of worms. For this purpose, a model of a system of two variable-pitch cone worms with the thread surfaces written in the same coordinate system was developed (Figure 6). Then, the profiles and inter-thread clearance of the worms were determined in the planes parallel to the common axial plane of the worm system (Figure 7). Calculations carried out confirmed the possibility of worm profiles intersecting in a non-axial section (Figure 8). In such a case in practice either the worm cuts are widened or the profile angle is changed using the trial and error method. In order to eliminate this phenomenon, a bevel (of approx. 4 mm) is made on the worm thread crests.

The developed program allows the elimination of the thread profile intersection phenomenon in mating worms at the worm design stage through the appropriate modification of the worm geometric parameters [14].

CONCLUSIONS

Variable-pitch cone worms used in plastic extrusion presses are technologically difficult to made and are cut on special CNC machine tools. The applied technology of finishing machining of a worm with a conical finger-type cutter is inaccurate due to hard tool operation conditions.

A program has been developed, which enables the use, besides conical finger-type cutters of a fixed geometry, also conical and cylindrical finger-types cutters with an enlarged diameter and an increased number of blades, which should contribute to enhancing the accuracy and productivity of the machining.

A program for the determination of the inter-thread clearance between mating worms has been developed, which enables the clearance to be accurately determined already at the stage of designing worms and their technology, thereby enhancing the accuracy of their execution.

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Note: The responsible lector is from Czestochowa University of Technology