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Contributions to systemic analysis for worm screw production using thread whirling devices

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Abstract. The paper aims to achieve a systemic analysis of worms processing using whirling threaded devices with highlighting all the factors involved in this system. It will also carry out an analysis of these factors depending on specific conditions such machining. Are also presented the stages of experimentation program and ways of processing for data obtained.

1. General considerations

The general scheme of the technological process is shown systemically in figure 1, where:

- $x_1, x_2, ..., x_{n1}$ – input parameters of the technological system;
- $y_1, y_2, ..., y_{n2}$ – output parameters of the technological system;
- $z_1, z_2, ..., z_{n3}$ – internal controllable parameters;
- $w_1, w_2, ..., w_{n4}$ – internal uncontrollable parameters.

These parameters may be grouped into independent and dependent parameters.

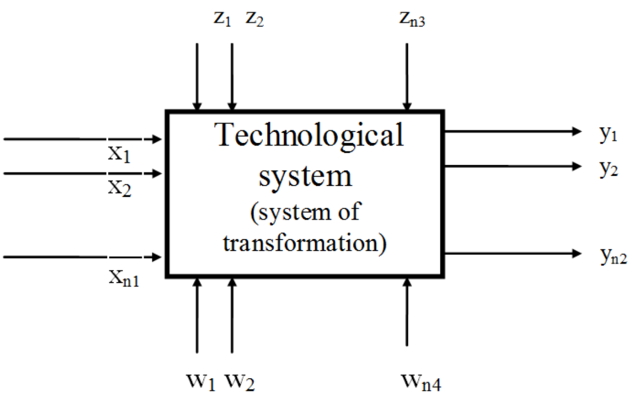

Figure 1. Systemic scheme for the technological process.

The independent parameters are the so-called "inputs" into the technological system and include the totality of parameters that may be modified in a controlled manner and the dependent are the objectives or the outcomes of the technological process. Parameters w_1, w_2, ... w_{n4} usually are neglected in designing the mathematical model. Such a model needs to make a relation between the dependent variables y_1, y_2 ....y_{n2} and the independent parameters. As such models are complex and hard to design and use, we often use the models of the following type:

$$y_i = f\left(x_{1i}, x_{2i}, \ldots x_{ni}\right) \tag{1}$$

Such models are deducted for specific values of known variables xi. For the complete description of the relations in the studies technological system, besides relations 1, called also objective function, restrictive functions are also established defining the limits within which the obtained relations are valid by the mathematical modeling of the process.

The selection of technological system parameters is a key issue in the further unfolding of the experiment. The ability of the mathematical model to reflect the most important phenomena in the studied technological process depends on the correct choice of these parameters

In selecting the input parameters, we should consider the easiness of their changing and measuring and their ability to influence significantly the technological process. Also, these factors should not have functional dependencies among them.

The selection of dependent parameters is made depending on the followed optimization objectives. The entire organization of experiments and the strategy for designing the mathematical model depend on them. They represent the output values and are generally the economic parameters (productivity, quality, cost) or parameters referring to behaviour in exploitation.

In the initial phase, we consider a high number of input parameters to be able later to select from them the parameters that have the highest influence on the output parameters. After choosing the input parameters, it is necessary to specify the limits between which each of them can take values.

These limits are set either for technological reasons or by the analogous results of similar experiments. The number of values that each parameter can take in the variation range either is also determined for technological reasons or based on the condition that the successive values should cause a significant variation of the dependent studied parameter. .

The whirling machining is a splintering process used more in thread and screw processing, which, through the advantageous trajectory of hard-blade knives, performs a high frequency interrupted splintering. Through the whirling machining of screws, we may obtain very good processing time, high accuracy of flanks (4 ÷ 7 precision steps) and a very good surface quality (Ra = 3.2 ÷ 0.8 μm). It is considered the most productive process for processing screws.

The name ”whirling” comes from the vocabulary of hunting weapons craftsmen who saw, at least initially, a resemblance with screw processing using screw threads. The part rotates relatively slowly and is eccentrically encircled by the tough blade knives rotating at a high speed so that each blade enters into splintering regularly, on the 1/4÷1/6 of the circle circumference on which the tool rotates.

Tool cooling is particularly advantageous and it is done on the free knife motion. This allows the use of higher splintering speeds than in other types of machining.

Generally, the swirl heads have 4 to 8 knives, the most common being 4 knives. The number of knives is limited by their size and the possibility of ensuring precise positioning within the spindle of the device. If the positioning is made by optical means, the number of knives used is limited to 4.

For machining, generally, knives with metal carbide blades are used.

Worm machining after the swirling process can be done:

a) on universal lathes on which swirl devices are mounted (Burgsmüller und Söhne system);

b) special whirling machines (Waldrich Coburg system).

Swirl machining can be performed according to two schemes, depending on the tangent mode of the bottom of the screw and the displacement of the knife tips:

- by outer tangent;
- by inner tangent.

Swirl machining with outer tangent is similar to cutting using disc milling. Swirl machining with inner tangent is also called enveloping milling.

To study the physical phenomena specific to this machining, we should consider several specific features:

- in splintering simultaneously are only some knives of the threading heads (generally one knife);
- each blade enters periodically into splintering;

- the rotation speed of the swirl head is high, which ensures very good heat evacuation;
- the machined addition removed from each of the knives increases from zero to a maximum, then decreases to zero again;
- machining can be done in the direction of feed or advance. The wear type of the knives is directly related to the two types of splintering.

When machining against the feed, the main component of the splintering force opposes the feed movement and takes over the movements from the advancement movement mechanism (the main shaft of the lathe) which results in the reduction of vibrations.

When machining in the direction of the feed, the main component of the splintering force has the same direction as the feed motion and cannot retrieve the grip from the feed motion mechanism. For this reason, in this type of machining, to pick up the movements from the kinematic chain of the main shaft, there are used devices picking up these movements.

The screw profile can be obtained with knives with the same profile as the hollow (blades with full profile or with split blades).

Chip formation in full-blade knives is more difficult than in knives with a split profile. When machining screws after this process, the chip has the form of a comma, its thickness rising from 0 to amax value, then it decreases.

The moment of the start of splintering, when the chip thickness increases from zero to a_{max} value exceeding the edge of the cut, is characterized by intense knife wear. This phenomenon is more intense when working with full-blade knives.

The warming up of the workpiece during machining is a particular problem especially in long spiked axes, the expansion caused by the temperature increase can cause the blade to bend and produce major machining errors.

Since at current working modes, the propagation rate of heat in the material is less than the feed rate of the workpiece, the piece remains cold, the entire amount of heat released at splintering being eliminated by the chips, which are released at machining.

2. The systemic structure of the machining process using thread whirling devices

The grouping of parameters involved in the technological process of screw making using this process according to the classification made in this chapter is shown in figure 2. The parameters of the shown technological system are grouped into:

a) input parameters:
- thread head speed n_m;
- c n_s;
- splintering depth a_p.

b) status parameters influence the unfolding of the machining process and they cannot be changed during work. In this category we can include:
- the characteristics of the semi-finished material (type of material, semi-fabrication, chemical composition, initial hardness, machinability, etc.)
- tool construction parameters (cutting edge angles, plate type, plate clamping);
- the structural parameters of the auger (axial mode mx, diametral coefficient q, number of beginnings z_1, coefficient of displacement x, normal pressure angle α_n, precision degree, hardness on the flanks, etc.)
- the characteristics of the used swirl spindle (geometric accuracy, vibration behavior, actuator characteristics, diameter of placement of the knife tips D_{vs});
- the precision of the lathe on which the swirl attachment is mounted;
- the temperature in the working area;
- the type of feed used for machining (advance processing, machining against advance).

c) output parameters:
- productivity of machining;

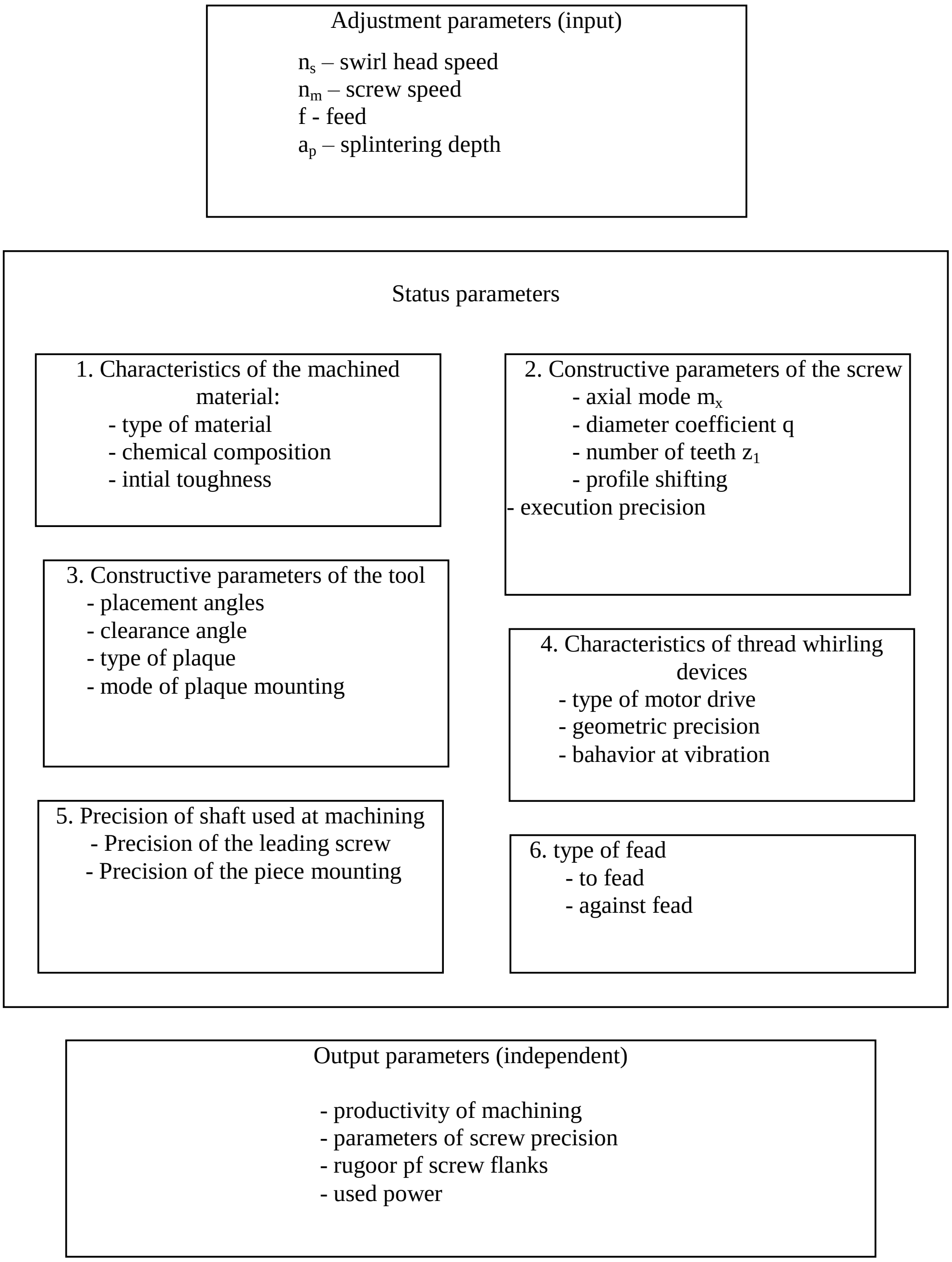

Figure 2. Systemic structure of the machining process with thread whirling devices.

- accuracy of the resultant auger (radial teeth, axial pitch deviation, profile deviation, spindle deviation, spiral deviation, minimum spline thickness deviation);
- flank roughness;
- wear of the cutting tool;
- used power.

2.1. Input parameters

1. Thread head speed (n_s)

It is a parameter that is directly related to the speed of splintering. This parameter is generally not adjustable in thread whirling devices, it is given by the engine speed that has at most two gears. In order to enable the variation of the speed on the experimental device, several belt wheels with different primitive diameters were made to study the influence of this input parameter on the output parameters. On this basis, it is possible to determine the speeds that ensure optimal speeds corresponding to specific machining cases.

2. Main shaft speed (n_m)

The main shaft speed is a parameter that is directly related to the feed on the tooth f_z. Depending on the geometric characteristics of the machined screw, the main shaft speed is interdependent with the longitudinal feed of the lathe sleeve. Therefore, for the study of the output parameters it is sufficient to enter one of the two input parameters. It has been preferred to introduce the main shaft speed independently as it is directly related to the feed on the tooth.

3. Splintering depth (a_p)

Total splintering depth is given by the geometric characteristics of the auger and its execution technology. In single pass machining, the splintering depth is equal to the total splintering depth.

If after the swirl machining, there follow other finishing operations of the worm teeth, then the splintering depth decreases with the value of the machining addition required for these operations.

2.2. Status parameters

1. Characteristics of the semi-finished material

The material from which the piece is to be executed gives these characteristics. For semi-finished material machining, it is necessary to know its chemical composition, production method, hardness and machinability. In order to establish start-up splintering conditions, in research conducted into machining using thread whirling devices, we considered the existing research in the literature in the field on the machinability of materials commonly used in the screw manufacturing. Experimental research has been carried out for each type of studied material.

2. Screw constructive materials

These parameters are included in the execution drawing of the screw. In order to investigate the machining process for a large range of screws, we considered the values of the axial modules mx fitting into the outer diameters of the screws within the limits allowing marching on the designed device. Since the diametral coefficient has only one value indicated to be mainly used for each axial module (STAS 6845-82), this parameter was not taken as a variable parameter during the experiments.

The number of beginnings does not essentially change the machining problems in terms of productivity and precision. For designing screws with several beginnings, it is needed to use an indexing device Experiments have been carried on screws without profile shifts, being considered that the machining process is not significantly influenced by this parameter. The used pressure angle was the standard one (α_n=20°).

The precision achieved by the thread whirling technique was followed to determine if a required screw to be achieved in a certain precision step can be made using this technique.

3. Tool constructive parameters

These parameters influence the splintering process considering the specific conditions for swirling machining, the angles of the splintering tools have been set in accordance with the values recommended for machining with splintering plates.

4. Characteristics of thread whirling devices

These directly influence the parameters of the splintering conditions that may be used for machining. Whirling machining is a discontinuous process, it is important that the device is rigid enough to pick up vibrations resulting from splintering. The precision of the knife positioning influences the geometric accuracy of the screw (deviation of the profile, minimum deviation of the thickness of the spindle). The dispensing diameter of the knife tips is generally as low as possible for the splintering to take place on a large circle arc, thus reducing the vibrations. This diameter is therefore directly related to the geometric constructive parameters of the screw. Experiments have been conducted for different blade tip diameters for the same type of screw, which have highlighted the need for it to be physically closest to the outer diameter of the machined screw, while allowing the piece to be removed from the device and easy

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handling of the commands. The drive motor of the device must provide the power required for machining the maximum size screws that can be made on the device.

5. Lathe precision

The precision of the lathe influences the precision of determining the depth of splintering and the precision of obtaining the axial pitch of the screw.

Determining the correct depth of splintering influences the minimum deviation of the thickness of the spindle. The precision of the axial pitch is given by the precision of the screw of the lathe and its wear during operation.

The method of semifinished item mounting influences the radial jaw of the screw teeth.

6. Type of feed used in machining

It is a status parameter that was taken into account in order to make a comparison between feed and against feed machining. Being a two-level parameter, experiments were performed to compare the two machining methods.

It was found that when machining using thread whirling devices, the thermal energy produced in the splintering area is transmitted in particular to the chips released during machining, the piece and the tool taking up a small amount of this energy.

As long as in whirling machining, the feed speed, measured on the division speed is higher than the propagation speed of the heat in the material, the piece remains cold.

Tool cooling is particularly advantageous due to the high rotation speed of the device head, as well as due to the fact that each knife cuts only about a quarter of rotation time.

2.3. Output parameters

1. Machining productivity

It is the main factor that determines the choice of a particular machining process for making an item. The machining of screws with thread whirling devices is the most productive method of screw machining. The productivity can be assessed by the time required to carry out the worm gearing operation, by the unitary time required to perform the machining, through the basic time required to splinter the teeth, etc.

2. Screw precision parameters

These parameters can be grouped into:

- precision parameters that depend on the thread whirling device and the operating mode used;
- precision parameters that depend on the precision of the lathe on which the device is mounted.

From the first group, we will study the deviation of the profile of the auger and the minimum deviation of the thickness of the spiral. In the second group we can include the teeth radial beating, the axial pitch deviation and the screw propeller deviation.

These parameters will be studied to characterize the precision of the resulting auger without being included as dependent parameters of the studied technological process.

3. Wear of cutting tool

The wear of the cutting tool will be considered for determining the cutting speed in economical conditions. Knowing the knife wear values, their life time can be precisely determined.

4. Used power

This dependent parameter is studied both for the determination of cutting conditions with as low as possible energy consumption and for correct determination of the drive motor power equipping a device designed to machine parts in a specific range of external diameters

5. Surface roughness

Among the parameters characterizing the quality of the surface obtained after machining, the parameter Ra. was calculated. The evolution of roughness was monitored in accordance with the parameters of the cutting conditions and the geometric outflow of the screw.

After establishing the parameters involved in the technological process of machining screws using thread whirling devices, it is necessary to order them in accordance with the aims. For each dependent parameter, the independent parameters on which they depend are set.

Technological processes are complex processes and consequently can not be studied without introducing simplifying assumptions.

One of the main problems of technological process research is the establishment of technological parameters that meet certain requirements regarding the productivity and quality of the obtained parts. This research should be carried out with the least amount of work and lowest expenses.

These requirements impose the use of statistical and mathematical models deduced from the observations and measurements made on the studied technological process. This requires performing some successive operations that can be grouped in several steps:

- technological process establishment;
- performing experiments after designing a plan;
- deduction of mathematical relations of the model;
- verification of the deduced mathematical model.

Difficulties that arise are given by the fact that each dependent parameter is also related to certain status parameters. If all these dependencies are considered, there will be experimental programs with a great deal of experiences, and the mathematical processing of the results leads to complicated models with reduced utility. Therefore, we intended to obtain fractional models, and in a later phase to include all the factors that characterize the complex model.

With the development of computer engineering, the statistical processing of experimental data has developed strongly, being widely recognised that this processing requires a large amount of calculations. Many of the current data processing can not be conducted without the help of the computer. The evolution of statistical processing programs followed the development of computers. Out of the many existing programs around the world, we refer to the integrated software Mathematica, the complete statistical software Statgraphics and the interactive software Matlab.

3. Conclusions

Problems related to statistical processing of experimental data are complex and occur in all phases of experimentation (experiment programming, deployment, data processing).

The systemic analysis of the technological process for machining screws using thread whirling devices reveals the multitude of factors involved in the process. In view of the above, we have managed to simplify the model by taking into account only the essential factors directly dependent on the thread whirling device.

Experimental data processing programs cam model mathematically the studied process by analysing a high number of functional dependencies covering a wide range of parameters. The volume of calculations made has been very high and the addressed issues need high performance computers.

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