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CORRELATION BETWEEN PARAMETERS AND KINEMATICS ON THE DESIGN OF CONSTANT PITCH SPIRAL-TURNED ORNAMENTS

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Rezumat. *Execuţia torsadelor cu pas constant presupune descrierea de către scula prelucrătoare a unei traiectorii elicoidale (directoarea) dispuse pe un cilindru. Scula prelucrătoare are materializată pe cuţitele tăietoare forma profilului înfăşurării elicoidale a torsadei (generatoarea). Generatoarea şi directoarea reprezintă elementele de bază în prelucrarea torsadelor cu pas constant. Dacă generatoarea este materializată pe cuţitele tăietoare ale sculelor prelucrătoare (freze profilate cu coadă), directoarea trebuie generată cinematic prin combinarea unor mişcări realizate de către sculă şi piesa prelucrată. Generarea directoarei elicoidale presupune combinarea unor mişcări liniare şi unghiulare, corelate parametrial în funcţie de caracteristicile geometrice ale torsadei: unghiul de înfăşurare şi pasul înfăşurării (pasul axial). Lucrarea îşi propune să prezinte legăturile şi corelările parametriale ale sculelor prelucrătoare şi ale pieselor prelucrate în conformitate cu elementele geometrice ce trebuie să rezulte pentru asigurarea esteticii ornamentului. Corelările parametriale au în vedere şi obţinerea calităţii dorite a suprafeţelor prelucrate. Toate acestea presupun realizarea unor corelări parametrial-cinematice ale maşinilor unelte specializate, capabile să efectueze prelucrări pentru astfel de ornamente.*

Abstract. *Execution of spiral-turned ornaments with constant pitch represents the movement of the tool on the helical trajectories (main trajectory) along a cylinder during manufacturing process. The processing tool has the profile shape of the helical winding (generated trajectory) on the cutting knives. The main and the generated trajectories are the basic elements in processing of spiral-turned ornaments with constant pitch. If the generated trajectory is materialized on the cutting knives of the tools (profiled router milling tools), the main trajectory must be kinematic generated by combining the movements performed by the tool and the workpiece. Generating the main trajectory means to combine the linear and angular movements, correlated with parameters as function of geometrical characteristics of the spiral-turned ornament: wrapping angle and winding pitch (axial pitch). This paper aims to present the links and parametric correlations between the working tool and the workpiece according to the geometric characteristics that must result to ensure the aesthetics of the ornament. The correlation of parameters results also in obtaining the desired quality of machined surfaces. All these require the development of correlation between kinematics and parameters of the machine tools that process such ornaments.*

Keywords: spiral-turned ornament, kinematics, feed speed, rotation

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1. Introduction

Processing of spiral-turned ornaments, as well as of any profiled surface (plane or three dimensional one) means to generate windings with pre-defined constant pitch on a helical trajectory processed on cylindrical elements [1, 2].

The section (the profile) of the wounded element is the “generated trajectory”, whilst the helical trajectory of the generated winding is the “main trajectory”. In the technique of processing the profiled surfaces, the main and generated trajectories are kinematical obtained by combining movements (linear or angular).

When processing the spiral-turned ornaments, the generated trajectory (the profile shape) is materialized on the cutting knife of the tool, as seen in Fig. 1.

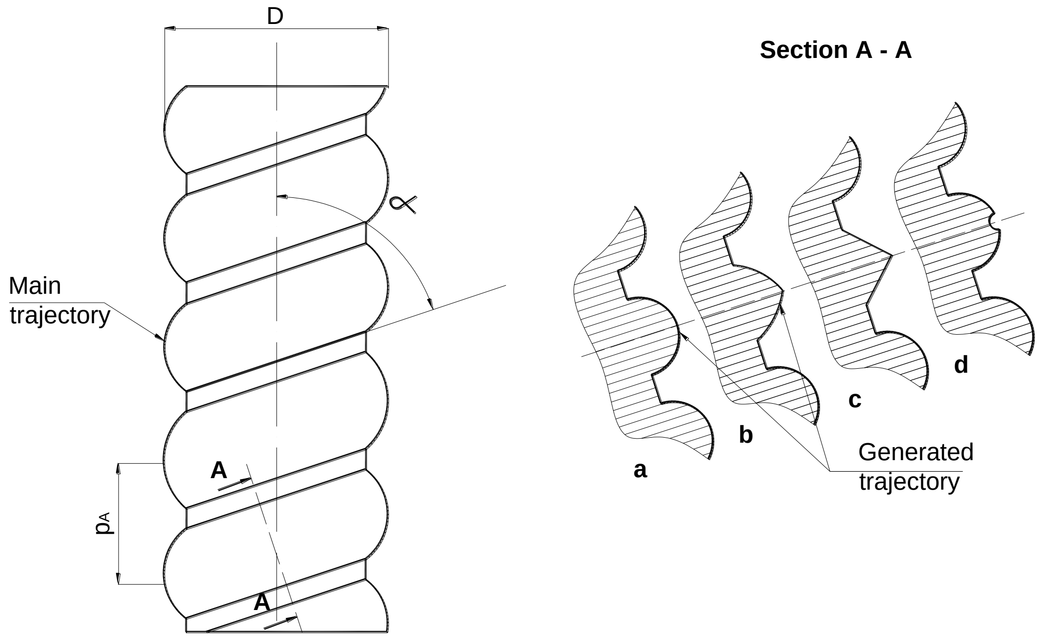

Fig. 1. Generated and main trajectories of the spiral-turned ornament with constant pitch; $\propto$ –winding angle; p_A- axial pitch; D – diameter of the cylinder.

Processing of a winding results in processing of both flanks (left-right) by one, two or more successive operations as function of distance a between two adjacent windings measured at their bases and a_0, the size of processing tool.

As seen in Fig. 2, two successive operations are necessary to process the windings (Fig. 2b), when the equation $a \leq 2a_0$ is valid, where a is the distance between two adjacent windings measured at their bases and a_0, the diameter of the processing tool tip.

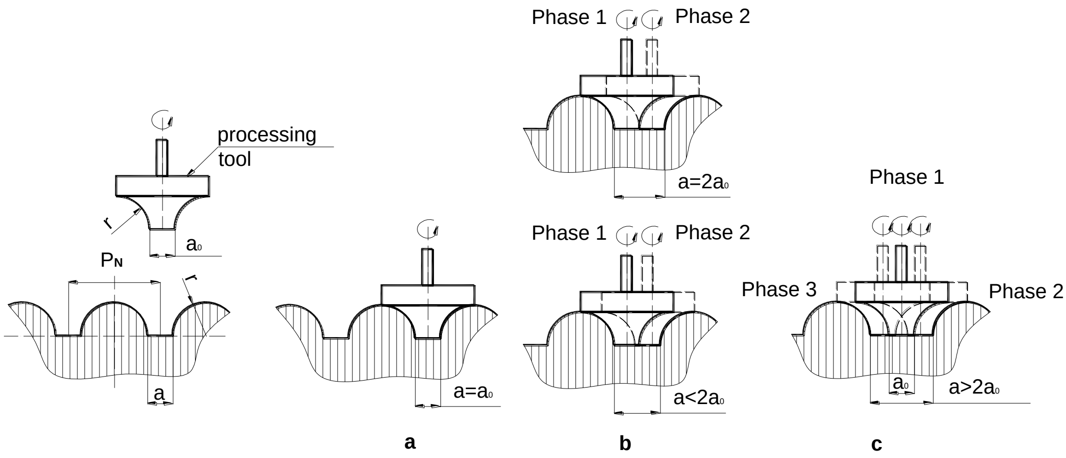

Fig. 2. The geometry of the generated trajectory and the relationship with the geometrical elements of the processing tool.

When $a > 2a_0$ more than two processing phases of the tool are necessary to obtain the winding along the main trajectory (Fig. 2c).

The simultaneous processing of the two adjacent flanks of the profile is possible only in the case when $a = 2a_0$ (Fig. 2a) in a single processing phase.

In order to increase the productivity when processing the spiral-turned parts with constant pitch, the remarks presented above have to be taken into consideration since the design phase [1, 2].

The main trajectory is kinematic generated by the constant feeding linear movement of the processing tool (a router milling tool having also a rotation speed) and a constant rotation speed of the workpiece. The combination between the two constant movements results in the processing of the helical trajectory with constant axial pitch on the cylinder surface.

The combinations of the two movements (linear and rotation ones) depends on the winding inclination and on the axial pitch of the ornament. These movements are obtained by kinematics correlations in the structure of the processing equipment.

Considering the constant values to be followed during machining the spiral-turned parts with constant pitch (characterized by the winding angle and axial pitch values) and including the case when these values change with the modification of the geometric characteristics of the ornament, the appropriate combinations can be obtained using the kinematic scheme presented in Fig. 3.

The kinematic structure resulted from the general kinematic scheme includes the main components able to meet the following requirements:

- A linear feeding speed of the tool (u_s) parallel to the axis of the workpiece, constant during the machining process, with the possibility of adjusting the constant and controlled values, using the variation element EV_1 (friction based mechanical variation device) according to the manufacturing conditions (axial pitch, inclination angle of the spiral-turned ornament and workpiese rotation);
- A tangential feed speed of the tool for the helical trajectory, imposed by the quality conditions required by the flanks of the ornaments and controlled by EV_2, which defines the rotation of the workpiece and the feed speed [2] on the helical trajectory and also the axial pitch.
- Possibility of processing spiral-turned parts having more parallel windings (beginnings) by adjusting *ED* dividing device.
- Possibility of processing spiral-turned parts having both left-right inclination directions, by adjusting EI_v inverting device.
- Possibility of processing spiral-turned ornaments with various inclination angles (different from a part to another), using the variation element EV_2 correlated to the variation element EV_1.

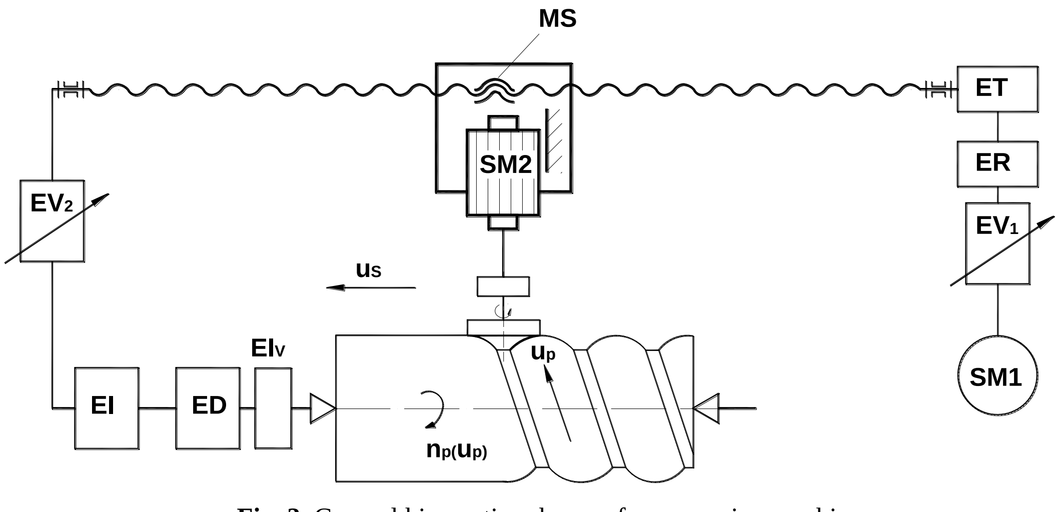

Fig. 3. General kinematic scheme of a processing machine for spiral-turned ornaments with constant pitch.

The structure presented in general kinematic scheme [2] can meet all the requirements needed to process the spiral-turned ornaments, containing all the necessary components to provide the processing movements (through the energy sources SM_1 and SM_2), to modify the characteristics of the movement (through the variation devices EV_1 and EV_2 and the reducer device *ER*), to change the rotation movement into linear one and vice versa (*SM* = movement screw) and to change the movement direction (movement inversing device EI_V).

Selection of the devices necessary for transferring the movement (*ET*) and the values can generate several structure combinations, so to design kinematics of the processing machines used for the execution of spiral-turned ornaments with constant pitch [2].

2. Correlation of kinematic parameters for processing spiral-turned ornaments with constant pitch

The main kinematic parameters when processing the spiral-turned parts with constant pitch are as follows: linear feeding speed of the tool along the processed workpiece (u_s) and the feed speed of the tool along the helical trajectory against the processed workpiece (u_p).

As seen in Fig. 3, the linear feed speed of the tool is provided by the movement screw (*SM*) and the processing feed speed (u_p) of the tool along the helical trajectory is provided by the resultant of combining the rotation speed of the workpiece (tangential speed u_t) and the linear feed speed of the tool u_s. Having the details presented in Fig. 4, the first correlation between the parameters and kinematics can be done according to equation 1:

$$u_p = \sqrt{{u_s}^2 + {u_t}^2} \text{ where } u_p = \frac{u_s}{\cos\alpha} \text{ and } u_p = \frac{u_t}{\sin\alpha} \quad (1)$$

where:
u_p is the feed speed of the tool during machining on the helical trajectory;
u_s is the linear feed speed of the tool (component of processing speed) parallel to the axis of rotation;
u_t is the feed speed of the tool (belonging to the circumference) on the tangential direction to the circumference of the processed workpiece.

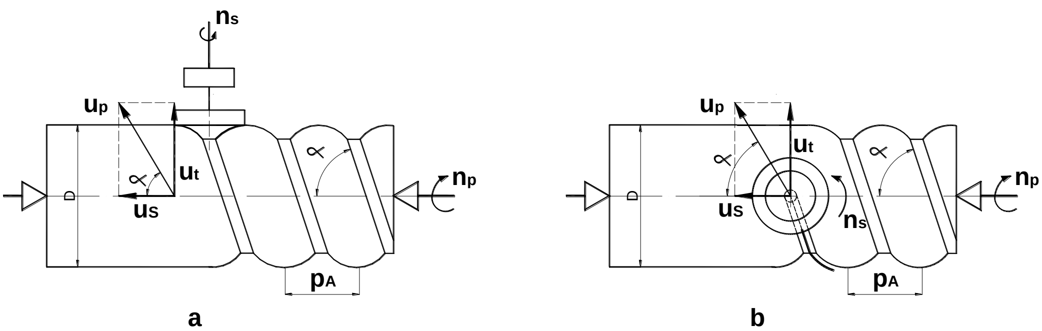

Fig. 4. Working scheme of processing the spiral-turned ornaments with constant pitch.

Starting with the hypothesis that the processing feed speed (u_p) of the tool along the helical trajectory has to provide the appropriate quality of the processed, it has to be defined [3, 4 , 5] according to equation 2:

$$u_p = \frac{u_z \cdot z \cdot n_s}{1000} \text{ [m/min]} \quad (2)$$

where:
u_z is the feed speed of the knife of the tool during machining, technological imposed and defining the quality of the surface resulted after processing the workpiece, in mm;
z is the number of knives of the processing tool;
n_s is the rotation speed of the tool, in rot/min.
The feed speed (u_p) is adjusted in order to correlate the machining process and the quality of the surface with the geometry of the ornament (D and $\propto$). For this purpose, devices EV_1 and EV_2, which are components of the kinematic scheme presented in Fig. 3 have to work in tandem. Taking into account that the rotation speed of the workpiece (n_p) is the parameter resulted as the adjustment of devices EV_1 and EV_2, the analysis will be conducted differently, as follows:

- The feed speed of the tool (u_s) must result as a correlation between the rotation of the movement screw (*MS*) and its axial pitch, according to equation 3;

$$u_s = n_{sc} \cdot p_{Asc} \tag{3}$$

where:
n_{sc} is the rotation speed of the movement screw;
p_{Asc} is the axial pitch of the screw.

- The feed speed of the tool (u_s) must result also as a correlation between the rotation speed of the workpiece (n_p) and axial pitch of the spiral-turned ornament, according to equation 4;

$$u_s = n_p \cdot p_A \tag{4}$$

From equations 3 and 4, equation 5 results, as follows:

$$n_{sc} \cdot p_{Asc} = n_p \cdot p_A \quad \text{or} \quad n_p = n_{sc} \cdot \frac{p_{Asc}}{p_A} \tag{5}$$

Equation 5 defines the parametric correlation between the rotation speed of the workpiece, the rotation speed of the screw adjusted by device EV_1 and the axial pitch of the screw p_{Asc} (Fig. 3).

Based on the general scheme in Fig. 3 and on the notation made in equation 6, the ratio between the rotation speed of the screw and the rotation speed of the part can be defined.

The value of this ratio is the adjustment value of device EV_2 (Fig. 3).

$$\frac{n_{sc}}{n_p} = \frac{p_A}{p_{Asc}} = i_{II} \tag{6}$$

As seen in Fig. 4b, the tangential feed speed of the tool (u_t) can be calculated with equation 7.

$$u_t = \pi \cdot D \cdot n_p \tag{7}$$

where:
D is the diameter of the workpiece, selected so to meet the quality requirements, in the conditions where the machining is performed on a diameter varying from D to D – r (at the base of the profile);
n_p is the rotation speed of the workpiece.

Based on equations 1 and 2, equation 8 results, as follows:

$$u_t = u_p \cdot \sin\alpha = \frac{u_z \cdot z \cdot n_s}{1000} \cdot \sin\alpha \tag{8}$$

Equation 8 defines the parametric correlation between the feed speed of the tool tangential to the workpiece, the quality of the surface defined by u_z and inclination angle of the spiral turned ornament, $\propto$.

Considering equation 7 and 8, the correlations in equation 9 result, as follows:

$$\pi \cdot D \cdot n_p = \frac{u_z \cdot z \cdot n_s}{1000} \cdot sin\,\alpha \quad \text{or} \quad n_p = \frac{u_z \cdot z \cdot n_s}{1000 \cdot \pi \cdot D} \cdot \sin\alpha \tag{9}$$

Equation 9 defines the parametric correlation between the rotation speed of the workpiece in order to obtain the quality conditions during the machining of the part (imposed by u_z) and the geometric elements of the spiral-turned ornaments, D and $\propto$.

Based on equations 9 and 5, the following equations result:

$$n_{sc} \cdot \frac{p_{Asc}}{p_A} = \frac{u_z \cdot z \cdot n_s}{1000\pi D} \cdot \sin\alpha, \text{ or} \tag{10}$$

$$n_{sc} \cdot i_{II} = \frac{u_z \cdot z \cdot n_s}{1000\pi D} \cdot \sin\alpha, \text{ or} \tag{10'}$$

$$i_{II} = \frac{u_z \cdot z \cdot n_s}{1000 \cdot n_{sc} \cdot \pi \cdot D} \cdot \sin\alpha, \tag{10''}$$

Equation 10” defines the parametric-kinematics correlation of the ratio to be transmitted between the rotation axis of the movement screw and the rotation axis of the workpiece, adjusted by EV_2 (Fig. 3). According to Fig. 4b, equation 11 can be written as follows.

$$u_s = u_p \cdot \cos\alpha = \frac{u_z \cdot z \cdot n_s}{1000} \cdot \cos\alpha \tag{11}$$

Based on equations 3 and 11, the following equation can be also written:

$$n_{sc} \cdot p_{Asc} = \frac{u_z \cdot z \cdot n_s}{1000} \cdot \cos\alpha \quad \text{o} \quad n_{sc} = \frac{u_z \cdot z \cdot n_s}{1000 \cdot p_{Asc}} \cdot \cos\alpha \tag{12}$$

Equation 12 defines the parametric correlation of the rotation speed of the movement screw (MS) with the kinematic elements imposed by the quality of the surface (u_z) and the geometric element of the spiral-turned ornament, namely the inclination angle, $\propto$.

Due to the fact that the movement screw is driven by the source of energy SM_1 (Fig. 3), which is an electric engine with a rotation speed n_0, than equation 13 is valid:

$$\frac{n_0}{n_{sc}} = i_I \tag{13}$$

where:
i_I is the transmitted ratio between the rotation axis of the electric engine and the rotation axis of the movement screw, adjusted by EV_2 (Fig. 3).

Based on equation (12), the transmitted ratio can be calculated with equation 13'.

$$i_I = \frac{1000 \cdot p_{Asc} \cdot n_0}{u_z \cdot z \cdot n_s \cdot \cos\alpha} \tag{13'}$$

Based on the equations presented above, in order to correlate the parameters and kinematics of the elements (Fig. 3) and to obtain the appropriate quality of the winding surface and the geometric parameters of the spiral turned ornament, an algorithm of calculating and adjusting the parameters of the kinematic structure can be established.

3. Algorithm of calculating and adjusting the parameters and kinematics

The geometric parameters of the spiral-turned ornaments with constant pitch to be processed (D, $\propto$, p_A) are those on which the adjustment of the parameters and kinematics is based on, according to the structure presented in Fig. 3.

Adjustment of the parameters and kinematics when processing the spiral-turned ornaments with constant pitch is based on the following steps:

- To establish the geometry of the ornament (D, $\propto$, p_A), as input data, according to the documentation;
- To establish the input data of the machine that processes the spiral-turned ornaments with constant pitch:
  - n_0 – the rotation speed of the electric engine that drive the movement screw;
  - p_{Asc} – the axial pitch of the movement screw;
  - n_s – the rotation speed of the processing tool;
  - z – number of knives of the processing tool.
- To establish the class of quality of the surfaces of the flanks of the spiral-turned ornament – by choosing u_z value (feed speed of the tool knife) for the milling operation.
- Calculus of the rotation speed of the movement screw, using equation 12:

$$n_{sc} = \frac{u_z \cdot z \cdot n_s}{1000 \cdot p_{Asc}} \cdot \cos\alpha$$

- Calculus of the transmitted ratio i_I using equation 13, for which the device EV_1 (Fig. 3) has to be adjusted and the adjustment of EV_1 at the calculated value i_I.

$$i_I = \frac{n_0}{n_{sc}}$$

- Calculus of the rotation speed of the spindle that drives the workpiece, using equation 9;

$$n_p = \frac{u_z \cdot z \cdot n_s}{1000 \cdot \pi \cdot D} \cdot \sin\alpha$$

- Calculus of the transmitted ratio i_{II} adjusted by the device EV_2 (Fig. 3) and the adjustment of EV_2 at the calculated value i_{II} according to equation 6;

$$i_{II} = \frac{n_{sc}}{n_p}$$

- Calculus of the feed speed along the trajectory, according to equation 2.

$$u_p = \frac{u_z \cdot z \cdot n_s}{1000} \text{ [m/min]}$$

- Calculus of the tangential feed speed according to equations 7 and 8.

$$u_t = \pi \cdot D \cdot n_p \text{ [m/min] or}$$

$$u_t = \frac{u_z \cdot z \cdot n_s}{1000} \cdot \sin\alpha$$

- Calculus of the axial feed speed, according to equations 3, 4 and 11:

$$u_s = n_{sc} \cdot p_{Asc}, \quad \text{or} \quad u_s = n_p \cdot p_A, \text{ or}$$

$$u_s = \frac{u_z \cdot z \cdot n_s}{1000} \cdot \cos\alpha, \quad \text{or} \quad u_s = \frac{u_z \cdot z \cdot n_s \cdot p_A}{1000 \cdot \pi \cdot D} \cdot \sin\alpha$$

From the analysis of the general kinematic scheme presented in Fig. 3, the phases of the adjustment resulted are as follows:

- To make the calculations as presented in the above presented algorithm;
- To adjust device EV_1 at the calculated value i_I.
- To adjust device EV_2 at the calculated value i_{II}.

The next step is to fix the workpiece on the processing machine. After that, the next phases are to be followed:

- The dividing device *ED* is adjusted in the position defined by the number of the beginnings of the spiral-turned ornament (number of the parallel windings).

- The indexing device *EI* is adjusted by coupling it on the rotation axis of the workpiece.
- The rotation direction of the workpiece (left or right) is adjusted as function of the spiral inclination by the inversing device EI_V.
- The workpiece is processed on a helical trajectory.
- The initial position is restored, than a new adjustment of *ED* is done for a new beginning, the device *EI* is adjusted and a new winding is processed.

Depending on the correlation between a and a_0, the processing is conducted on several phases (I, II or more), as presented in Fig. 2, positioning *ED* for these processing phases.

Conclusions

The correlation between parameters and kinematics when processing the spiral-turned with constant pitch ornaments needs the following requirements:

- a technical drawing of the ornament, where geometric parameters (D, $\propto$, p_A) are designed in order to fulfill the correlation of the geometry and parameters of the ornament [1];

- a specialized machine for processing the spiral-turned ornaments, where the basic kinematic parameters are as follows: n_0, p_{Asc}, ratio of adjusting EV_1 ($i_{Imin} \rightarrow i_{Imax}$), ratio of adjusting EV_2 ($i_{IImin} \rightarrow i_{IImax}$).

- a processing tool characterized by the following elements: z – number of cutting knives, a_0, r);

R E F E R E N C E S

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