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CYLINDRICAL GEAR TOOTH PROCESSING BY HOBBING CUTTER ON CNC LATHES

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Abstract: *The papers highlights principles an correlations imposed to the generation motions of the spur gear teeth on CNC lathes. Some specific to CNC lathes kinematic structures are presented. The kinematic structure of the lathe consists of rotation and translation couples. The relations that contain the constructive parameters of the tool and workpiece and also of the generation kinematics are determined. The input variable of the kinematic chains are supplied by electric motors with continuous adjustable speeds. For emphasizing the processing possibilities of the tooth flanks, a kinematic structure of a CNC revolver lathe is considered and also its kinemtic couples, generation motions and speed adjustment possibilities.*

Key words: *generation motions, kinematic structure, kinematic and technological parameters, gear, CNC lathe*.

1. INTRODUCTION

1.1. Generalities

The increasing complexity of the parts influenced the conception, kinematic and control structure of all machines [4]. Among them there are the revolver lathes in a great diversity of dimensions and processing possibilities [5]. Some CNC lathes constructors emphasize their possibility of processing cylindrical gears by milling with hob cutter, toothed sector, and also worm wheels.

The gear processing operation by milling with hob cutter is subsequent to the turning, boring, and milling of the part. In most of cases, the gear is integrated in a part of shaft or bushing type [Fig. 1]. Depending on configuration (Fig. 1), the part is completely processed in the same clamping or in two chucks on the same machine. Therefore, the processing accuracy is increasing by eliminating or diminishing the clamping errors or of machine adjustments. Such lathes [9] have 5 CNC axes, three of translation and two of rotation, like in the case of conventional [2, 3] and CNC gear processing machines by milling with hob cutter [6].

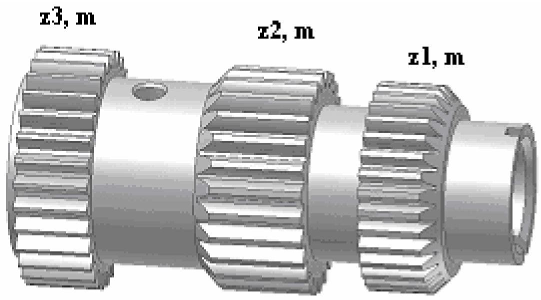

Fig. 1. Example of part processed on a CNC lathe.

1.2. Methods for processing gears by hob cutter

The processing of the spur gears with helical or straight teeth is done with axial, radial, or diagonal feed.

The processing of the spur gears with axial feed could be done with up milling or down milling. The machining cycle is of the type:

- rapid approaching;
- axial feed motion;
- rapid withdrawal;
- rapid withdrawal in the initial position.

The interpolation function *Ga* correlates the revolution speeds of the tools and workpiece. *Ga* is a special function in the programming language of the CNC equipment.

The processing of the spur gears with radial feed reduces the axial feed movement of the tool, enabling the increase of machining productivity. The machining cycle is of the type:

- rapid approaching;
- radial feed;
- axial speed;
- radial rapid withdrawal;
- axial rapid withdrawal in the initial position.

Applying a diagonal milling method is difficult to be implemented in the CNC equipment due to complexity of conditions between the generation motions.

2. GENERATION KINEMATICS

The cylindrical gear flanks are defined by two generation curves: the generatrix (profile) which is an normal involute, and directrix (flank line) which is a line or a cylindrical helix (in the case of helical spur teeth).

2.1. Generation kinematics of the spur gears

The position between the tools *T* and part *P* represented in Fig. 2., corresponds to the case in which the wheel is a spur gear, and the hob cutter has a right helix. The involute profile of the flanks is kinematically generated by rolling with mobile line [1] and continuous dividing. The rolling condition is enabled by the relation:

$$\frac{n_P}{n_T} = \frac{k_T}{z_p}, \qquad (1)$$

where n_P represents the part speed, n_T – tool speed; k_T – number of helixes of the hob cutter; and z_P – part tooth number. Hob cutter is selected from catalogues, being mainly defined through the diameter D_T, number of teeth z_T = 8–12, modulus m_T, the angle of inclination of the chip evacuation grooves γ.

The transfer ratio of the Botez mechanism formed by the tool and part is expressed by the relation:

$$i_w = \frac{v_r}{\omega_P \cdot r_r} = 1 = \text{constant}, \qquad (2)$$

where $v_r = n_T\, k_T\, \pi\, m_T$ is the speed of the rack moving profile; ω_P – angular velocity of the par and $r_r = (m_P\, z_P)/2$ – part rolling circle radius.

The hob cutter axis positioning in regard with the workpiece (Fig. 2) is done so that the profile of the generating rack (according to STAS) to be in the normal plane on the tooth helix. In this plane, the pitch $p_P = m_P\, \pi$ of the workpiece is defined. Therefore, the axial speed $y_{tP} = v_{aT} \cos\gamma = p_{aT}\, n_T$ has to be equal to the tangential speed of the processed gear, but

$$p_{aT} = \frac{p_P}{\cos\gamma} \cdot = \frac{m_P \pi}{\cos\gamma}. \qquad (3)$$

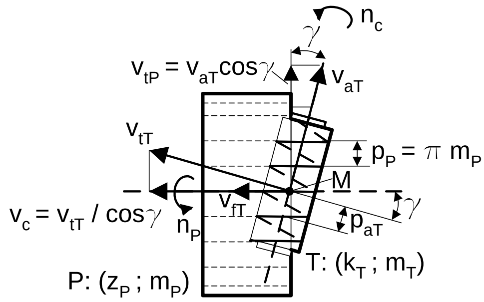

Fig. 2. Generation kinematic of the spur gear.

These conditions enable the rolling without sliding between the rolling circle of the workpiece and the reference line of the generating rack materialized on the tool.

Therefore, the axial speed in the normal plane on the tool helix is

$$p_{aT} = \frac{p_P}{\cos\gamma} \cdot n_T \cdot \cos\gamma = p_P \cdot n_T \qquad (4)$$

and depends on the modulus of the processed teeth.

The feed speed of the tool v_{fT} along the rotation axis of the workpiece is considered constant having a technological value. Its direction could have the same direction or contrary direction as the cutting speed. The value of the feed speed does not influence the speed values that enable the kinematic generation of the involute profile and the linear flank line parallel to the workpiece axis. The v_{fT} speed influences the real cutting speed resulting form the summation of the cutting speed and feed speed

The speed v_{fT} is chosen from technological reasons, also the real cutting speed (the algebraic sum of v_c and v_{ft} depending on the method of milling, namely up milling or down milling). Therefore, the speed v_c is involved in the calculation relation of tool speed n_T:

$$n_T = \frac{1000 \cdot v_c}{\pi \cdot D_T} \text{ [rpm]}, \qquad (5)\backslash$$

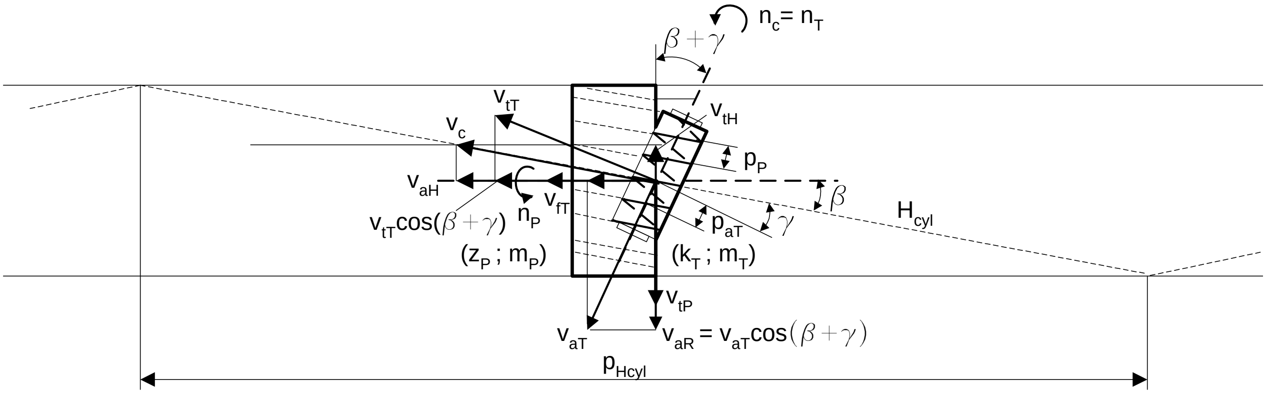

Fig. 3. Generation kinematic of the helical spur gear.

where D_T is the tool diameter. Then, the workpiece speed n_P is determined with the relation (1). Also, the speed v_{fT} determines the speed of the electric motor of the axial fee kinematic chain (axis *Z*).

2.2. Generation kinematics of the helical gears

The tool axis (Fig. 3) is inclined with regard to the frontal surface of the part with the angle $\beta \pm \gamma$, where *P* is the tooth inclination angle. The two helixes (of the part and tool) have the same direction or opposite directions. The tooth flank line is a part of the cylindrical helix H_{cyl}, curve kinematikally generated.

The position between the tool *T* and part *P* corresponds to the case in which the part has a cylindrical helix on the left and the hob cutter a tooth helix on the right (Fig. 3). As in the case of spur gears, the generatrix is an involute curve. The profile is kinematically generated by rolling with mobile line and continuous dividing. The rolling condition [1] is achieved also through the relation (1). The helix H_{cyl} having the pitch p_{Hcyl} is generated by two continuous correlated motions, namely one of translation (axial with regard to the part – tool feed motion with the speed v_{fT}) and the other one of revolution characterized by a tangential speed v_{tP}. The pitch p_{Hcyl} is expressed by

$$p_{Hcyl} = \frac{\pi \cdot D_P}{\tan\beta} = \frac{\pi \cdot m_a \cdot z_P}{\tan\beta} = \frac{\pi \cdot m_n \cdot z_P}{\sin\beta}\,. \qquad (6)$$

The speed v_{fT} determines the value of the speed v_{tH}, between them existing the relation (threading condition):

$$\frac{v_{tH}}{v_{aH}} = \tan\beta\,, \qquad (7)$$

from where we can obtain

$$\begin{aligned} v_{aH} &= v_{tT}\cos(\beta+\gamma) + v_{fT} = \\ &\pi \cdot D_T \cdot n_T \cos(\beta+\gamma) + f_P \cdot n_P \tan\beta \end{aligned}\,. \qquad (8)$$

The factor f_p is the feed per one workpiece revolution.

The simultaneously generating of the two curves (the profile and flan line) implies the correlation of the generation motions of rotation (n_P, n_T) and translation (v_{fT}). Regarding the tool, the speed n_T determines the axial speed v_{aT} having the projection on the front plane of the part v_{aR}.

The speed n_P has two virtual components corresponding to the two generation curves.

Therefore, for achieving the rolling condition, two speed have the same value:

$$v_{aR} = v_{tH} \mp v_{tP}\,, \qquad (9)$$

where

$$v_{tP} = \pi \cdot D_P \cdot n_P = \pi \cdot m_P \cdot z_P \cdot n_P$$

and v_{tH} is given by (8).

The speed v_{aR} has the expression

$$v_{aR} = v_{aT}\cos(\beta \pm \gamma) = p_{aT} \cdot n_T \cdot k_T \cdot \cos(\beta \pm \gamma)\,. \qquad (10)$$

The relation (9) becomes considering the direction of too and part helixes as follows

$$\begin{aligned} &p_{aT} \cdot n_T \cdot k_T \cdot \cos(\beta \pm \gamma) = \pi \cdot m_P \cdot z_P \cdot n_P - \\ &[\pi \cdot D_T \cdot n_T \cos(\beta \pm \gamma) + f_P \cdot n_P]\tan\beta. \end{aligned} \qquad (11)$$

Different signs could be considered in the relation depending on the right or left orientation of the tool and workpiece helixes, and also of up or down milling process.

From it the workpiece speed derives as

$$n_P = \frac{n_T\cos(\beta \pm \gamma)(p_{aT} \cdot k_T + \pi \cdot D_T \tan\beta)}{(\pi \cdot m_P \cdot z_P - f_P \cdot \tan\beta)}\,, \qquad (12)$$

depending on two technological parameters (n_T and f_P) and also on geometric parameters of the tool and part (p_{aT}, k_T, D_T, β, γ, $m = m_P = m_T$, z_P).

2.3. Generation kinematics of worm wheels

The worm wheel processing could be done by the two known methods – with radial or tangential feed [1].

The processing with radial feed is achieved continuously on a distance greater than the tooth height. The motion distance being small, the productivity is good. The tooth accuracy of the worm wheels is low. When the tool reaches the position according to the required distance between the axes of the tool and workpiece, the radial feed stops and the rolling process continues for finishing the tooth flank. for a better accuracy the methods with tangential feed or by using shaving with a worm shaver are used.

The processing with tangential feed of the hob cutter having a conical front section, enables keeping constant the distance between the tool and workpiece axes, therefore the processing accuracy is good. The motion length of the hob cutter in tangential fee motion is big, so that the machining productivity is good but smaller than in the first case, the tool life being increased.

For the displacement of the hob cutter with an axial pitch given by

$$p_a = \frac{\pi \cdot m_n}{\cos\gamma}\,, \qquad (13)$$

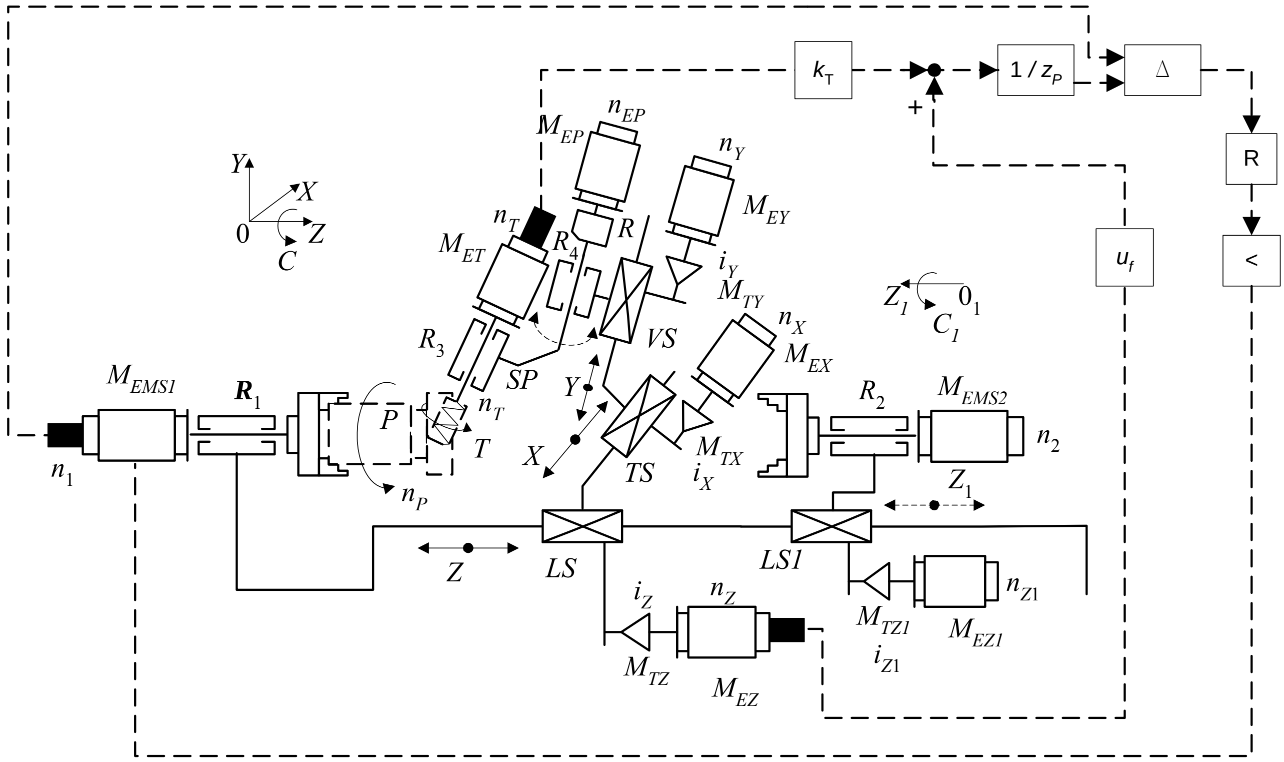

Fig. 4. Kinematic structure of a CNC revolver lathe. with mixed association kinematic chains for cylindrical gear tooth processing:

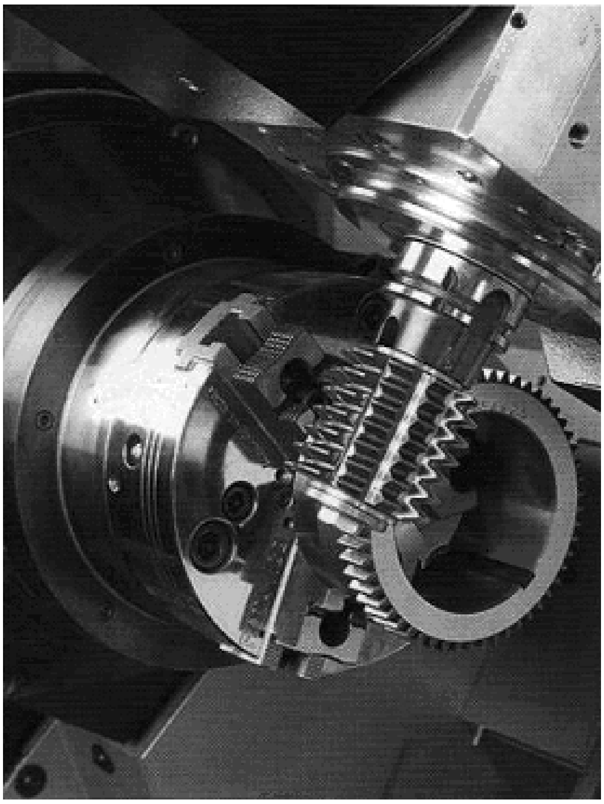

Fig. 5. Tool and part in gear processing on a CNC lathe [10].

the workpiece turns continuously with an angular pitch (360° / z_p) in the time given by relation:

$$t = \frac{p_a}{v_{aT}}. \tag{14}$$

For the speeds correlation one has to take into consideration that the rolling motion of the generation element depends on the axial speed of the tangential motion.

3. KINEMATIC STRUCTURE OF THE MACHINE

The CNC lathes, on which the processing of spur gears by milling with hob cutter is possible, achieves the following generation motions (Fig. 4):

- main rotary motion of tool *T* with speed n_T, which is also the cutting speed n_c, supplied by an electric motor M_{ET} directly or through a reducer placed on a support *Sp* attached to the vertical slide *VS* (axis *Y*) having a feed motion or a angular positioning one;
- circular feed motion (axis *C*) of the part *P* with the speed n_P, obtained by the main electric motor M_{EMS1} of the lathe; in this case it does not work as a main kinematic chain but as circular feed kinematic chain; it is used also as main motion in turning;
- longitudinal feed motion (axis *Z*) achieved by the longitudinal slide *LS*, driven by the electric motor M_{EZ} through a mechanism M_{TZ} of ball spindle-nut having the transfer ratio i_Z;
- transversal feed motion (axis *X*) achieved by the transversal slide *TS*, driven by the electric motor M_{EX} through a ball spindle-nut M_{TX};
- angular positioning motion of the hob cutter axis depending on the inclination angle β of the part teeth

and angle of chip evacuation channels γ; the motion being supplied by the electric motor M_{EP} through a reducer of worm and wheel type *R* having the ratio i_R.

An example of positions of the tool and part involved in gear tooth machining on a lathe is presented in Fig. 5.

4. FLEXIBLE ASSOCIATION OF KINEMATIC CHAINS

4.1. General aspects

When we refer to classical machine tools dedicated to gear cutting, the kinematic chains for rolling or threading, etc. are rigidly connected to each other, the adjustment of each of them being achieved by means of changeable mechanical transmissions, usually change gears. Due to this hard connection between the kinematic chains, their association is called rigid.

In CNC gear cutting machines, we need also to keep the correlations on the basis of geometric and kinematic parameters, but the connection between the kinematic chains is done by means of the CNC equipment. Therefore, the association of the independent kinematic chains is called flexible or soft (the operator changes only some parameter in program or using directly an interface panel. All these aspect are specific also to CNC lathes that have the capacity of cutting gears.

The flexible CNC association of the kinematic chains of lathes (Fig.4) refers to the following aspects:

- the kinematic structure of the machine tool is constituted only by independent generating kinematic chains (main and feed chains),
- simple structures of the kinematic chains due to the adjustment achieved only electromechanically or electrically,
- he kinematic closing condition imposed by the generation of the curves *G* and *D* is easily achieved through the CNC equipment,
- if in rigid association the input values Y_i of the two associated kinematic chains le are subject of a rigid connection (L_R, L_F), in association with flexible program the connection is pseudo-elastic,
- possibility of identification, reducing and compensating for in real time the errors caused by static, dynamic and thermal behavior of the mechanisms in the kinematic chain structure.

4.2. Implications in the CNC programming language

For machining gears on lathes, the CNC equipment has to allow the following specialized addresses:

- M auxiliary functions for selecting/deselecting of the milling module;
- M auxiliary functions for blocking/unblocking the axis *B*;
- auxiliary functions for starting/stopping the revolution motion of the milling main spindle;
- G preparing functions for selecting / canceling the gear processing by milling with hob cutter;
- a group pf addresses for selecting the tooth modulus, main spindle axis, workpiece spindle axis, revolution direction for these spindles, number of helixes of the hob cutter, workpiece tooth number, angle of inclination of the hob teeth helix, angle between the too and workpiece axes.
- selection of the axis of milling 0 spindle (+1 for the milling axis as main axis in tooth processing).
- selects the part axis and its direction of motion (± 1 for the axis C1 of the main spindle on the left, ± 2 for the axis C2 of the main spindle on the right);
- (+) corresponds to the same direction of revolution for tool and part, to enable the processing of the teeth with inclination in one way, the sign (−) corresponds to the opposite directions of revolution s of the tool and part that enables the processing of the teeth with inclination in opposite direction;
- number of starts k of the hub cutter (up to 20);
- number of the part teeth z_p;
- modulus or Diametral pitch (*m* or *Dp)*;
- angle of inclination of he helix of the part teeth p in degrees, having positive sigh (+) for right helix and negative for left helix;
- positioning angle of the tool with regard to the part axis for the inclined teeth.

5. CONCLUSIONS

The cutting of gears on CNC horizontal lathes is necessary for complete processing (turning, drilling, milling and tooth milling) for the same part clamping. Therefore, the inherent setting errors are eliminated that appear in machining part on more than one machine tool.

The processing of the spur gear teeth belonging to some parts of shaft or disc type on the same lathe, on which first the turning was achieved, enables the increase of productivity (by eliminating the auxiliary times for removing, transport and setting the part on other machine tool) and the accuracy (by eliminating the setting errors on other machine too).

The kinematic structure, the motions and their speeds, and necessary correlations between the speeds of different electric motors with continuous adjusting speeds enable the required kinematic and technological conditions.

In the paper, the necessary correlations between the speeds of the driving electric motors of the CNC lathe were determined. The relations are used for the design of the interpolators of the CNC equipment.

The analysis and results presented prove the importance of the numerically control in eliminating the laborious calculations necessary for setting the classical gear processing machines, among them the hob milling machine. Also the heavy change wheels sets that supply the required pairs of change wheels for a certain calculation and used for setting the kinematic chains of the machine are also removed.

REFERENCES

[1] Botez, E. (1969), *Maşni-unelte, Vol. I, Cinematica* (Machine tools, Vol I, Kinematics), Edit. Tehnică, Bucharest.

[2] Pfauter, H. (1976). *Pfauter-walfrasen. Teil 1. Verfahren, Maschinen, Werkzeuge, Andvenngstechnik, Wechselrader* (Part 1. Processing, machines, tools, application techniques), Springer-Verlag, Berlin, Heidelberg, New York.

[3] Predincea, N., Ispas, C., Minciu, C., Ghionea, A., Maşala, I. (1995). *Lanţuri cinematice închise. Teoria asocierii* (Closed kinematic chains. Theory of association), Tehnologii, Calitate, Maşini, Materiale, No. 11, Edit. Tehnică, ISBN 973–31–0833–2, pp. 24–36, Bucharest.

[4] Perovic, B. (2006). *Handbuch Werkzeug-maschinen. Berechnung, Auslegung und Konstruction* (Machine Tools. Handbook. Calculation, selection and construction), ISBN 13:978–446–40602–2, Carl Hanser Verlag, München, Wien.

[5] Ghionea, A., Constantin, G., Catrina, D., Vintilescu, A., Popa L.C. (2007). *Configurations and modularization grade of some CNC turning machines*, Proceedings of the 17th International Conference on Manufacturing Systems – ICMaS, Edit. Academiei Române, pp. 39–44, ISSN 1842–3183, Bucharest.

[6] Predincea, N., Constantin, G., Ghionea, A. (2008). *Rigid and flexible association of kinematic chains in gear processing machines Computer aided design of NC machine tool gear boxes*, Annals of DAAAM for 2008 and Proceedings of the 19th International DAAAM Symposium, DAAAM International, Vienna, 2008, Published by DAAAM International, Vienna, Austria, Editor B. Katalinic, ISSN 1726–9679, pp. 1137–1138..

[7] Kief, B.H. (2001/02), *NC/CNC Handbuch* (NC/CNC handbook), Carl Hanser Verlag, ISBN 3–446–21756–8,Wien

[8] Sandu, C., Ghionea, A., Sandu, C.S. (2006). *Virtual hobbing machine*, Proceedings of the 15th International Conference on Manufacturing Systems – ICMaS, ISSN 1842-3183, Edit. Academiei Române, pp. 137-140, Bucharest.

[9] Litvin, F. (1994). *Gear geometry and Applied Theory*, Prentice-Hall, Inc., ISBN 0–13–21095–4, Englewood Cliefs.

[10]***Prospects: Monforts, DMG, Mazak, Mori Seiki, Okuma

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