Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
Make Harmony Between Technology and Nature, and Your Mind will Fly Free as a Bird
Annals of DAAAM International

POSSIBILITIES OF PROCESSING POLYGONAL SURFACES ON CNC LATHES

GHIONEA, A[drian] L[ucian]; CONSTANTIN, G[eorge] & PREDINCEA, N[icolae]

Abstract: *Polygonal surfaces processing is achieved on specialized machine tools or on CNC machine tools, the last ones being in the cathegory of multifunctional machines. These are enabled with a number of numerically controlled axes that allow the motion correlations or the achievement of the condition of generation of polygonal surfaces. As a particularity with regard to the common lathes, the kinematic structure has numerically controlled motion of the multiple cutter revolution (cutting motion). A case study reveals the necessity of defining the generation kinematics of the directrix D_P and in some cases generatrix G. This study is guiding in choosing the machinetool structure and CNC equipment.*

Key words: *polygonal surface, directrix, generatrix, kinematic structure, CNC lathe*

1. INTRODUCTION

Polygonal surfaces are produced by turning, milling, and grinding on conventional or CNC multifunctional specialized machine tools (***). Surfaces having polygonal and curved directory (ellipse, circle, epicycloids, etc.) with linear and curved generatrices (Ghiţă, 2001), from different parts have a functional role, which demands certain accuracy. Significant are part surfaces with polygonal directory that can be found in shaft-hub assemblies (Maşala et al., 1995; Wachter, 1987; ***). Such surfaces have to meet dimensional accuracy, shape and quality conditions (Wachter, 1987; Chen et al., 2009). Taking this into account and the type of production, the machine-tool and technological processes are chosen.

For the lathe processing of parts having regular polygons guiding surfaces, two variants are used to generate:

- stopping the part driving shaft, for each polygonal surface component milling. The tool does the main cutting motion and the longitudinal feed motion, followed by the angular positioning of the spindle and the cycle for each side of the polygon is repeated. It is applied on certain specialized or CNC lathes.
- without stopping the rotation motion (circular feed) of the part driving shaft, by cinematic generation of multiple curves by milling with milling head type tools having 1–6 teeth disposed on the peripheral surface (***).

For this approach, processing accuracy of each side of the polygon is lower (normal accuracy), but productivity is high and corresponds to the repetitive manufacturing requirements.

2. KINEMATIC GENARATION

2.1 Generation of the polygonal directrix

The principle of polygonal milling on a CNC lathe is similar to that applied to multispindle automatic lathes or some specialized machine tools. When machining with CNC lathes, the workpiece *P* having z_P edges and being driven by the main spindle *MS* of the lathe (Fig. 1,a) has the speed n_P (circular feed motion − axis C_1). Also, the tool *T* (milling tool) having z_T cutting edges is mounted on a location of the revolver head disc *RH* and driven through a device in rotary motion with the rotation speed n_T (cutting motion − axis C_2). For processing the polygonal surface in axial direction, the longitudinal feed motion (axis *Z*, longitudinal slide *LS*) is necessary. The positioning motion for achieving the distance $R_{rP} + R_{rT}$ is done by combining two motions given by the vertical slide *VS* (axis *Y*) and transversal slide *TS* (axis *X*).

The revolution motions n_T and n_P, in the same or opposite directions, have to achieve the condition n_P / n_{cT} = constant (integer in case of Fig. 1,b) (Maşala, 1995):

$$i = \frac{n_T}{n_P} = \frac{z_P}{z_T} \, . \tag{1}$$

This condition is determined by the kinematic generation of the elongated directrix D_P (Fig. 1,b). The direction of motions are considered for the case of up milling.

The speed ratio derives from relation

$$n_P / n_{cT} = R_{rP} / R_{rT} = z_T / z_P \, . \tag{2}$$

The radii ratio derives from angular displacements for up milling and fix workpiece ($\Phi_T / \Phi_P = R_{rP} / R_{rT}$) (Fig. 2).

The polygonal surface sides are realized as portions of the elongated trajectory D_P described by the cutting edges.

On the basis of relation (2), the most used polygonal surfaces with an even or odd number of sides can be generated. It is necessary to choose a tool with the number of cutting edges in order to have the lowest speed of the tool for keeping the appropriate tool wear. Correlation of tool speed and piece speed according to relation (1) is assured by numerical controlled axes (C_1 and C_2).

Considering the motion and notations from Fig. 2, one can determine the cutting speed vector considered at the generator point *M* on the directrix trajectory D_P. A point *N* belonging to the cutting edge, situated at radius R_T different from R_{rT} would describe a trajectory D_P elongated or shortened. Its parametric equations are:

$$\begin{cases} X_P = (R_{rP} + R_{rT}) \cdot \cos\Phi_P - R_T \cdot \cos\dfrac{R_{rP} - R_{rT}}{R_{rT}} \cdot \Phi_P \\ Y_P = (R_{rP} + R_{rT}) \cdot \sin\Phi_P + R_T \cdot \sin\dfrac{R_{rP} - R_{rT}}{R_{rT}} \cdot \Phi_P \end{cases} \tag{3}$$

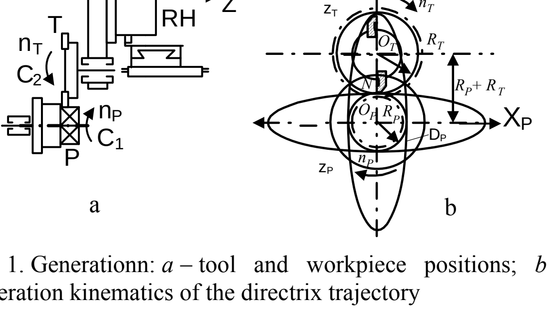

Fig. 1. Generationn: *a* – tool and workpiece positions; *b* – generation kinematics of the directrix trajectory

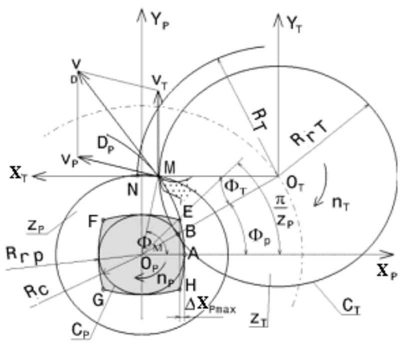

Fig. 2. Parameters of milling generation of polygonal directrix

If we have $R_T = R_{rT}$, the directix trajectory is normal being generated by the point M (on circle C_T).

For generation the directrix trajectories elongated or shortened for a workpiece defined by z_P and R_C in condition that it passes through the point A, it is necessary the appropriate positioning of the tool axis with regard to the workpiece axis. The radii R_{rT} and R_{rP} are in relation (2) from which it results:

$$R_{rT} = z_T(R_c + R_T)/(z_P + z_T)\,;\; R_{rP} = z_P(R_c + R_T)/(z_P + z_T)\,. \quad (4)$$

Thus, the relation (3) becomes

$$\begin{cases} X_P = (R_c + R_T)\cdot\cos\Phi_P - R_T\cdot\cos\dfrac{z_P \mp z_T}{z_T}\cdot\Phi_P \\ Y_P = (R_{rP} + R_T)\cdot\sin\Phi_P \pm R_T\cdot\sin\dfrac{z_P \mp z_T}{z_T}\cdot\Phi_P \end{cases}, \quad (5)$$

where the radii R_{rT} and R_{rP} are defined by relations (4).

If we have $R_T = R_{rT}$, the directix trajectory is normal being generated by the point M (on circle C_T).

The v_D vector components are v_P and v_T. The v_D vector modulus is calculated by the next formula:

$$\left|\bar{v}_D\right| = R_T\sqrt{\left(1+\frac{R_c}{R_T}\right)^2 + \left(\frac{z_P}{z_T}\mp 1\right)^2 \pm 2\left(1+\frac{R_c}{R_T}\right)\left(\frac{z_P}{z_T}\mp 1\right)\cdot\cos\left(\frac{z_P}{z_T}\right)\phi_P}\,, \quad (6)$$

where the upper signs are for up milling and the lower ones are for down milling. Because v_D depends on Φ_P, it varies during processing and influences the active cutting edge geometry.

Polygonal directories generated as cycloid trajectories portions are described by generating point M. The curvature radius of these trajectories is given by the following formula:

$$\rho = R_C\frac{\left[z_T(1+\frac{R_T}{R_C})^2 + (z_P - z_T)^2\cdot(\frac{R_T}{R_C})^2 + 2z_T\cdot\frac{R_T}{R_C}(1+\frac{R_T}{R_C})(z_P - z_T)\cdot\cos\frac{z_P}{z_T}\cdot\Phi_P\right]^{\frac{3}{2}}}{z_T^3(1+\frac{R_T}{R_C})^2 - (\frac{R_T}{R_C})^2(z_P - z_T)^3 + z\frac{R_T}{R_C}(1+\frac{R_T}{R_C})(z_P - z_T)(2z_T - z_P)\cos\frac{z_P}{Z_T}\cdot\Phi_P} \quad (7)$$

The deviation magnitude for a polygonal surface defined by z_P and R_C, depends on Φ_P, z_T and R_T and it can be positive or negative. If $z_P \le 2z_T$, the generated profile is always convex, no matter the value of the ratio R_T/R_C is.

In Fig. 3 it is shown the kinematic scheme of a CNC lathe with two opposite main spindles (*MS*) and two revolver heads (*RH*). The numerically controlled axes Y, X_1, Z_1, C_1, Z_2, X_2, C_2 are driven each by an electric motor. On this type of lathe one can apply the generation scheme on Fig. 1.

2.2 Polygonal surfaces having helical generatrix

In spiral polygon milling there is a combination of polygon milling and spiral milling (Paroz & Kohler, 2004). The spiral path (Fig. 3,a) along Z_1, can be done in two ways:

- an interpolation of the angle between the workpiece P and the tool T with the position of the axis Z_1, which cannot be realized yet due to the hardware limitations of the CNC;
- a correlation of the tool and workpiece motions so that their positions X and Y are interpolated to a circle of the position of Z_1, the tool center moving around the center of wokpiece (Fig. 3,b). The angle of sides depends on this rotation and also on the speed ratio and number of teeth of the tool.

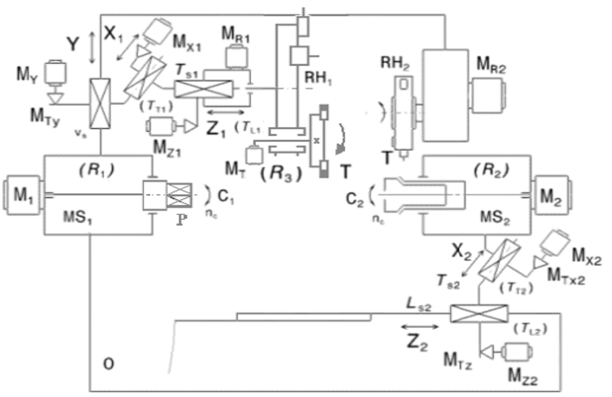

Fig. 3. Turret lathe with two coaxial opposite main spindles

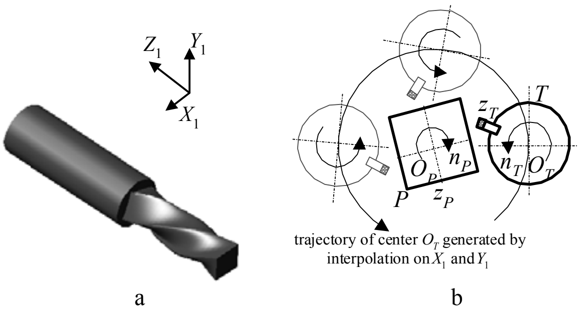

Fig. 4. *a* – example of part with polygonal-spiral surface; *b* – relative motions in spiral polygon milling.

3. CONCLUSIONS

The constructive parameters of the workpiece and tool and also the generation ones determine the form of the directrix and generatrix of the polygonal processed surface. The parametric equations of the directrix curve enable the determination of the components of the vector v_D, its director cosines and active angles of the cutting edges of the tool teeth.

The paper emphasizes for a case study the necessity of defining the generation kinematics of the curve D_P and in some cases of G. The presented study is guiding in choosing the machine tool structure and CNC equipment.

As further step it will be the continuation of the mathematic treatment that leads to the generation simulation, establishing some form errors and surface roughnes.

4. REFERENCES

Chen, D.; Lu, B. & Deng, X. (2009). Simulation and experiment of milling isometric polygonal profile based on NC method, *2nd IEEE International Conference on Computer Science and Information Technology, ICCSIT 2009*, pp. 537–541, ISBN: 978-1-4244-4519-6

Ghiţă, E. (2001). *Teoria şi tehnologia suprafeţelor poliforme* (Theory and technology of polyform sufaces), Editura BREN, ISBN 973-8141-07-1, Bucharest

Maşala, I.; Predincea, N.; Ghionea, A. & Aurite, T. (1995). Polygonal surface generating kinematics by milling, *Construcţia de Maşini*, Year XLVII, No. 3, Editor: OID-ICM Bucureşti, pp. 40–46, ISSN 0573-7419

Paroz, C. & Kohler, P-Y (2004). Forschung ist die Basis fuer Erfole im Markt (Research is the foundation for successes in the market), *Werkstatt und Betrieb*, August 2004, pp. 14–16, ISSN: 0043-2792

Wachter, K. (1987). *Konstruktionslehre für Maschinen-ingenieure* (Engineering design for machine engineers), VEB Verlag Technik, ISBN 3-341-00045-3, Berlin

*** Catalogs and technical documentations: Gildemeister, Pittler, Schüte, Index, Fortuna Polygon, Miyano, FastCut, Ph HORN Ph