Generation of the teeth precessional gears by plastic deformation

I Bostan[1], V Dulgheru[1] and N Trifan[1]

[1]Department of Basics of Machinery Projecting, Technical University of Moldova, Chișinău, Rep. Moldova

E-mail: nicolae.trifan@bpm.utm.md

Abstract. The paper presents a method for obtaining the teeth of the precessional gear by plastic deformation. There are analyzed the basic problems that must be resolved to apply this process: determination of dimensions of initial workpiece; choosing the correct machining regime; determination of necessary forces for material deformation for dimensioning of mechanisms used in machine-tool. The aim is obtaining of precessional gear wheel teeth, still from workpiece to ensure a minimum cost of machining and to improve operating conditions by providing a continuous material fibrillation.

1. Introduction

The quality of the car relies mostly on the high level degree of gearing. Transmissions through toothed wheels have gained a wider spread in machine's construction, with the widest range of power, torques and reliability. Gears are made of alloyed steels, and carbon steel, which are submitted to thermal, chemical treatment (cementation, nitration, cyanidation, and other methods.) When manufacturing toothed wheels, in principle, a distinction has to be made between the technology of the wheel body and the actual teeth technology. For the manufacturing of the wheel body, the working methods, which may be taken into consideration, are those generally used in machine building technology, especially casting and steel casting, forging and pressing. In this case, special problems for gears raise, in particular, the bodies made of welded elements, as well as the bodies of the gear wheels made through plastic deformation.

2. Determination of the linear velocity of the contact point of the tool with the blank

The speed of plastic deformation, has a major impact on the modification of the structure, and on the physical-mechanical properties of the deformed metal. Starting with the specificity of the spherical-space movement of the deformation tool, its linear velocity is determined by point D Figure 1 (a), which coincides with the center of the roller in the precession of the train gears [1]. From the angular velocity projection connexions, on the X, Y, Z, axes, we can obtain the linear velocity of the center of the deformation roll, noted by D, as follows:

-where R_D is the radius of the center O, around which the deformation roll effects spherical-space movement, up to point D.

$$V_{XD} = R_D \cdot \dot{\psi} \cdot \cos\delta \left[\sin\psi \cdot \sin\left(\frac{Z_1}{Z_2}\psi\right) - \frac{Z_1}{Z_2} \cdot \cos\psi \cdot \cos\left(\frac{Z_1}{Z_2}\psi\right) + \cos\psi \times \right.$$
$$\left. \times \cos\left(\frac{Z_1}{Z_2}\psi\right) \cdot \cos\theta - \frac{Z_1}{Z_2} \cdot \sin\psi \cdot \sin\left(\frac{Z_1}{Z_2}\psi\right) \cdot \cos\theta \right] - R_D \cdot \dot{\psi} \cdot \cos\delta \cdot \cos\psi \cdot \sin\theta;$$

$$V_{YD} = R_D \cdot \dot{\psi} \cdot \cos\delta \left[\cos\psi \cdot \sin\left(\frac{Z_1}{Z_2}\psi\right) + \frac{Z_1}{Z_2} \cdot \sin\psi \cdot \cos\left(\frac{Z_1}{Z_2}\psi\right) - \sin\psi \times \right.$$
$$\left. \times \cos\left(\frac{Z_1}{Z_2}\psi\right) \cdot \cos\theta - \frac{Z_1}{Z_2} \cdot \cos\psi \cdot \sin\left(\frac{Z_1}{Z_2}\psi\right) \cdot \cos\theta \right] - R_D \cdot \dot{\psi} \cdot \sin\delta \cdot \sin\psi \cdot \sin\theta;$$

$$V_{ZD} = R_D \cdot \dot{\psi} \cdot \frac{Z_1}{Z_2} \cdot cos\,\delta \cdot sin\left(\frac{Z_1}{Z_2}\psi\right) \cdot sin\,\theta \qquad (1)$$

Z_1-the teeth number of the fixed center wheel.

Z_2-the teeth number of the satellite crown in the precession gear. Making usage of expressions (1), the linear velocity of the center of the deformation tool noted by D will be:

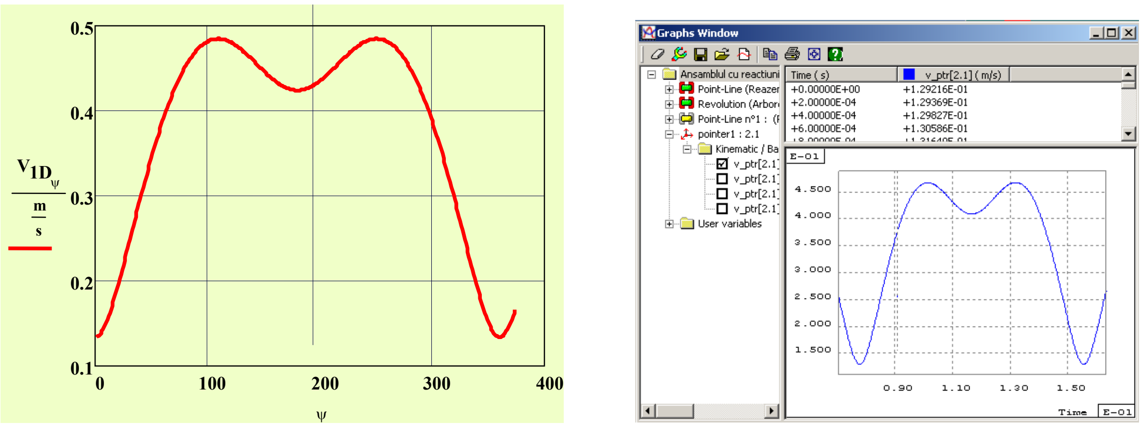
$$V_D = (V_{XD}^2 + V_{YD}^2 + V_{ZD}^2)^{1/2}$$

In the mathematical modelling package MathCad, the variation of the linear velocity of the point D, at rotative speed of the crankshaft of the deformation device presented in figure 1 (a). For comparison in figure 1 (b), it is presented a fragment of the results obtained by the numerical calculation method based on real time Autodesk Motion Inventor platform. The results obtained are identical, but Autodesk Motion Inventor performs also real time analyses and then can be used to develop dynamic models of tool-tooth interaction. For the study of the processes directly occurring in the tooth surface contact, it is necessary to determine the linear velocity variation of their E contact reported to a tool precession cycle (at a crank shaft rotation). The relative linear velocity of the tooth-tool is determined similarly to the relative linear velocity of point D, taking in consideration the following relationship:

$$V_E = \dot{\psi} \left(\begin{aligned} &\left(\frac{Z_1}{Z_2} sin\,\theta\, cos\,\psi\, Z_E - \left(1 - \frac{Z_1}{Z_2} cos\,\theta\right) Y_E \right)^2 + \left(\frac{Z_1}{Z_2} sin\,\theta\, sin\,\psi\, Z_E + \left(1 - \frac{Z_1}{Z_2} cos\,\theta\right)\right)^2 \\ &+ \left(\left(\frac{Z_1}{Z_2} sin\,\theta\, sin\,\psi\, Y_E + cos\,\psi\, X_E \right)\right)^2 \end{aligned} \right)^{1/2} \qquad (2)$$

3. Analysis of the influence of the tooth number on the linear deformation velocity

In order to model the influence of geometric parameters of the precession gear on the relative linear speed of the tool contact point E, with the convex-concave tooth, of the central wheel the Mathcad mathematical modelling package was also used. The method of performing all types of models is similar to the methodology adopted in modelling the relative linear velocity, centre of the tool. (point D).

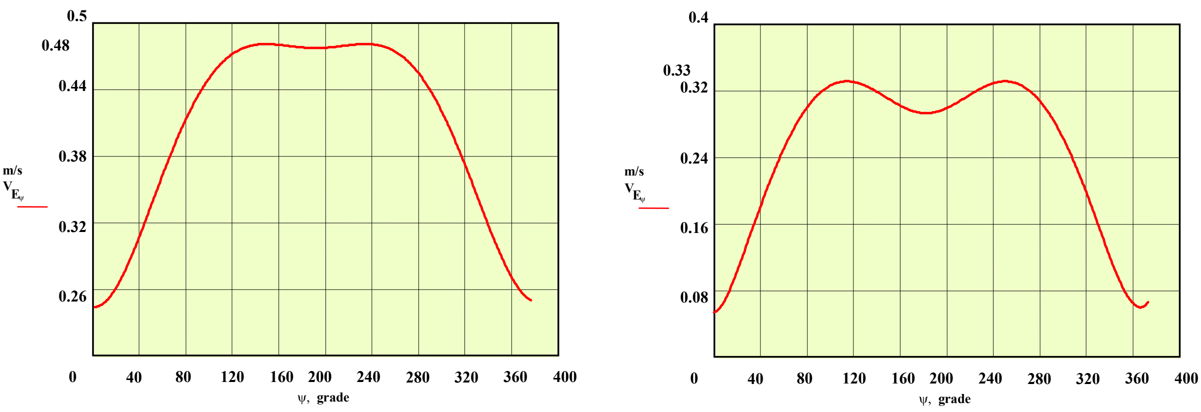


a) b)

Figure 1. Linear tool speed (p. D) in coordinate system X Y Z for constant geometric parameters: $Z_1 = 27, Z_2 = 28;\ \theta = 2^o30';\ \beta = 4^o;\ \delta = 22^o30';R_{out} = 100$ mm; n=800 rpm.

On the basis of the obtained relationship (2), a series of calculations were made for the determination of the relative linear velocity in „half manufactured tool" contact, varying the basic geometric parameters of the precession gear (δ, β, θ, Z), within the reasonable limits, established previously by acad. I. Bostan [1]; Z_1, Z_2 = 10 - 50; δ = 0 - 30º; β = 2º - 7º; θ = 1º30′ - 3º30′.
Due to the large volume of calculations in annexes, results are only presented for Z_1, Z_2=14 – 30, which are used more frequently in precession reducers and multipliers.

In figure 2 (a), (b.) two characteristic diagrams of the relative speed variation of the point contact (half manufactured tool) on the height contact point for two variants of tooth numbers: Z_1=14, Z_2=15; θ=2º30′;δ=22º30′; β=4º; R_{out}=147,5mm; n=400 rpm and Z_1=30; Z_2=31 - the rest of the parameters remaining the same. The qualitative analysis of the diagrams figure 2 (a), (b) shows that in smaller numbers of teeth, the relative linear velocity on the height of the tooth is more uniform than in the case of larger number of teeth. This aspect is important in order to reduce the dynamic demands of the technological equipment elements. The quantitate analysis of the diagrams demonstrated that the value of the relative linear velocity is higher for the smaller number of teeth.



a) b)

Figure 2. Linear speed of the "tool - semifabricate" contact point (p. E) for constant geometric parameters: θ = 2º30′; β = 4º; δ = 22º30′, n=400 rpm; R_{out} = 147,5 mm:
a) Z_1 = 14, Z_2 = 15; b) Z_1 = 30, Z_2 = 31.

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According to figure 2, the maximum relative linear velocity V_E (in the contact point tool-semi finished, is 0.48 m/s. According to [2, 3], plastic deformation is recommended at a working speed of 0.1....0.5m/s. These velocity regimes of plastic deformations ensure getting a cold-hardening layer of material, which can resist abrasion, fatigue, corrosion and has less plastic components.

4. Analysis of variance of plastic deformation velocity within a precession cycle

In order to work at the maximum recommended speed as to obtain high productivity, we must speed up the crankshaft variations. Determination of the plastic deformation velocity (the speed of a point on the surface of the plastic deformation roller) is similar to the determination of the linear velocity of a point situated on the surface of the conical roller in the procession gear [4]. In accordance with the methodology described, a multitude of diagrams of plastic deformation, of teeth (speeds representing an arbitrary point E situated on the surface of the deformation roll) were obtained. The diagrams obtained show that the plastic deformation velocities in the limits of a precession cycle are variable, as value and direction.

As the deformation velocity during a precession cycle has variations in order to respect optimal deformation regimes, it is necessary that the feed be variable depending on the variability of the relative working linear velocity V_E. Resuming, the correlation [V_E, s_{cpi}] must ensure the optimal flow of metal from the space between the teeth to their tip. As to achieve this purpose, the V_E velocity diagram figure 3, is divided in five sectors:

The sectors E_1E_2, E_2E_{n-k}, $E_{n-k}E_n$, E_nE_{m-1} and E_{m-1} E_m. The sectors E_1E_{n-k} and E_nE_m are similar (the linear velocities in the corresponding points E_1-E_m, E_2-E_{m-1} and $E_{n-k}E_n$) are equal but inverse as a direction, due to this aspect, on these sectors, the advance will be the same in the frame of each fragment (E_1E_2, $E_{m-1}E_m$) and will decrease over the sectors E_2E_{n-k}, E_nE_{m-1}.

In other words (s_{cpi} = f (V_{Ei}). If we take in consideration, the recommended deformation speed, should be within the range: (0.1-0.5 m/s).

In this case, the s_{cpi} V_E product should have a constant value for the given material, then the variation, of the advance to the formation of the h_{cpi} sectors will depend on the variation of the deformation velocity on the given sector, respecting the s_{cpi}-V_E-const product. On the E_{n-k} En sectors, the advance can be continuously accepted for the tooth profile category, where V_E can be considered constant. Ensuring the product s_{cpi} V_E - const, theoretically speaking, can be possible. In this case, the advance, must vary according to the inverse legality of the variation of the deformation speed.

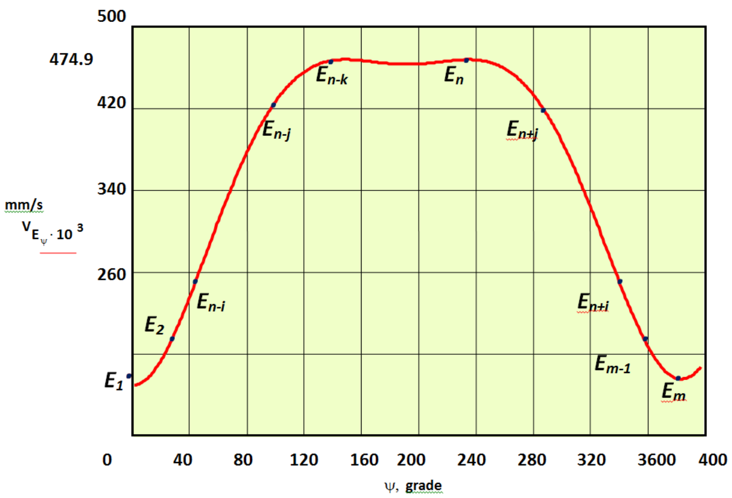

Figure 3. Speed chart by sectors.

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From the practical point of view of the technological process, the advance must be a constant size between the limits of a precession cycle. In this case, considering it, as the working advance, it will be taken the medium value of the advance on the working sectors E_{n-i}-E_{n-j} (in the case of irreversible precession transmission) or E_{n+i} – E_{n+j} (in case of reversible transmission) when the leading shaft rotates in both directions. These areas correspond to the most requested sectors on the working surface part of the teeth [5].

5. References

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