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FEM ANALYSIS OF THE SPUR GEARS PRESS–ROLLING PROCESS

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ABSTRACT

This paper presents the FEM (finite element method) analysis of the pressing-rolling process, a new method for obtaining spur gears. Using symmetries, the 3D geometrical model was created for tools and for the initial blank. The FEM analysis was carried out using Forge 2009, a specialized software for studying the plastic deformation processes. The objective of this study is to describe the evolution of the pressing and rolling forces in the press-rolling process.

KEYWORDS: FEM analysis, pressing, rolling, gear

1. Introduction

The main tooth forming techniques are casting, cutting, and forming processes (Fig. 1). Rolling techniques are divided into two categories as described in Fig. 2. According to this description press-rolling process is part of the forming techniques, more exactly, a longitudinal rolling process.

The rolling process is one of the forming processes used in industrial processing which has evolved over time from producing necessary prefabricated for other processes, finished products with simple shape, to obtaining products with complex shape and high dimensional precision complex form [2].

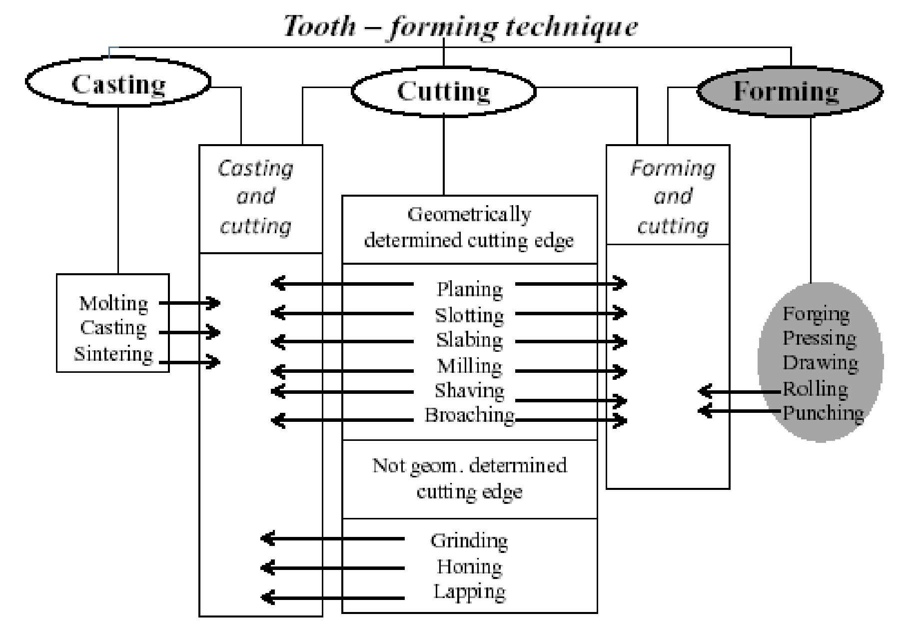


Fig. 1. *Tooth-forming techniques [1]*

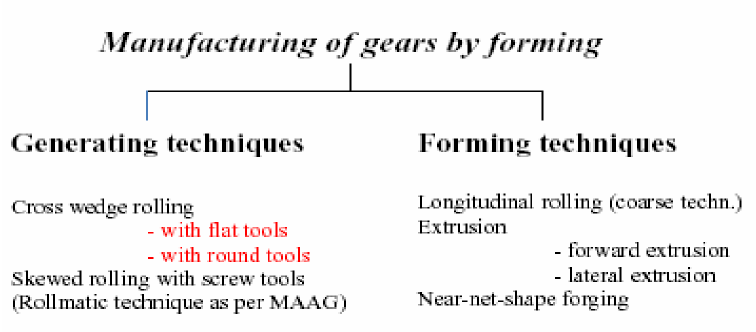
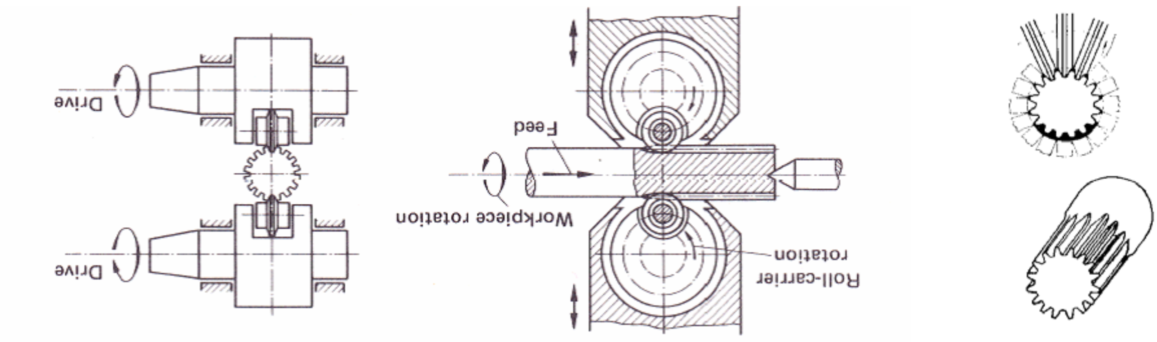


Fig. 2. *Various processes for gear manufacturing [1]*

By rolling we understand the deforming process supported by the metallic material passing through two or more rotating cylinders [3]. Longitudinal rolling with roll of grooved parts can be classified according to the manner of the deformation:

-superficial pressure (grooves are made successively (Fig. 3 a));

-deep pressure (grooves are made simultaneously (Fig. 3 b)). According to previous classifications, the press-rolling process (Fig. 4) to obtain spur gears is a longitudinal rolling process with deep pressing. Because in practice acting multiple cylinders (rolls) with rotation axis in the same plane is difficult, in the press – rolling process advance of work piece in the process and the friction between it and the roll, spinning the roll. So the study of this process is reduced to the study of longitudinal profiles rolling process with specification that this process takes place vertically direction, which means that the process is directly influenced by the weight of the work piece. To achieve simulation of the press-rolling process is necessary to describe the analytical model in order to calculate the rolling force and the pressing force.



a) b)

Fig. 3. *Longitudinal rolling of grooved parts with: a) superficial pressing [4] b) deep pressing [5]*

The rolling force in flat rolling is determined by the relationship:

$$F = n \cdot b_m \cdot \sigma_m \cdot l_c \qquad (1)$$

where: n number of rolls;

b_m average widening;

lc contact arc length

D_R roll diameter;

$$l_c \cdot b_m = S_c = \sqrt{\frac{D_R}{8}\left(D_s + D_i\right)} \qquad (2)$$

$$\sigma_m = \sigma_d\left[2\left(D_s / D_i\right)^{\delta} = 1\right] \qquad (3)$$

S_c – contact area;

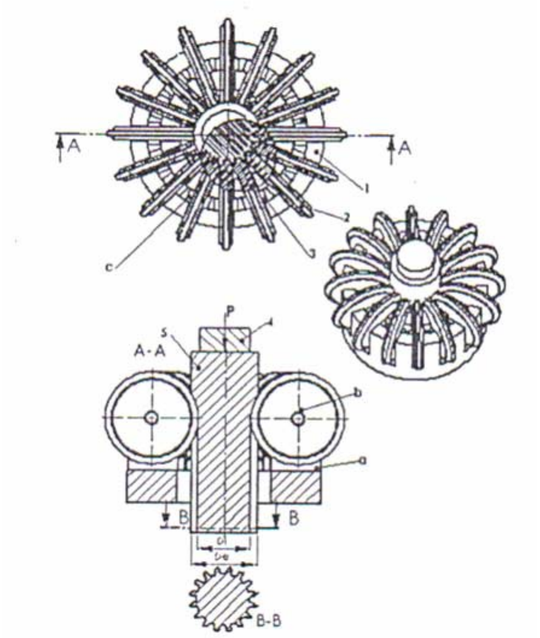
σ_m work piece average resistance to deformation;

D_S initial diameter of work piece;

D_i - inner diameter of the gear.

$$\delta = 1 + \frac{\mu}{tg\,\dfrac{\alpha}{2}} \qquad (4)$$

µ - friction coefficient and α the contact angle between roll and work piece.



Significance notations 1 - support, 2 - rolls, 3 - roller hub barrel type, 4 - puncher, 5 - cylindrical work piece, a-roll slot, b-circular bearing, c-bearing support for the barrel roll.

Fig. 4. *Press- rolling process [2]*

Pressing force is calculated using the equation:

$$P = P_D + P_a - G \tag{5}$$

where:

-P_d [2] the force required for material deformation from diameter D_S to diameter D_i;

$$P = \sigma_m \cdot \frac{\pi}{4}\left(D_s^2 - D_i^2\right) \tag{6}$$

- P_a [2] force necessary to overcome reactions from support is given by the relation;

$$P_a = n \cdot p_s \cdot S_c \cdot 2 \cdot \frac{\mu_f}{\alpha} \cdot \frac{d_f}{D_R} \tag{7}$$

- p_s - specific pressure;
- μ_f - coefficient of friction in the bearings;
- d_f - spindle diameter roll;
- p -specific pressure exerted on the roller
- G - work piece weight.

According to the laboratory work "Experimental Determination of the coefficient of friction in longitudinal rolling" the simultaneous measurement method of rolling force and the force of contraction [7], the coefficient of friction is calculated using the relationship and the Fig. 5.

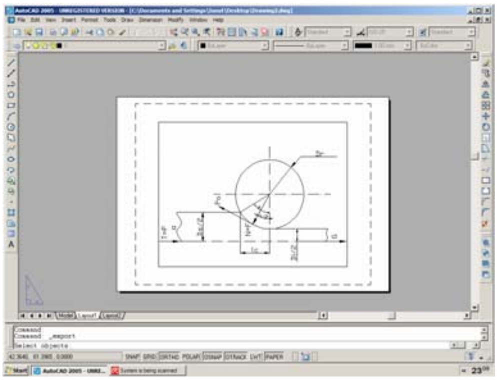


Fig. 5. *Graphical representation of forces in press-rolling process, longitudinal section*

where:

- F = N rolling force;

$$\mu = \frac{T}{2N\cos\frac{\alpha}{2}} + tg\,\frac{\alpha}{2} \tag{8}$$

- μ coefficient of friction, force of contraction;
- T for longitudinal rolling;
- α grab angle.

Considering the force of contraction T of the lamination process equal to the pressing force P from the press-rolling process and adding the necessary force to prevail the reactions from bearings and the force of gravity can be written:

$$P = nF\left(\mu - tg\,\frac{\alpha}{2}\right)\cos\frac{\alpha}{2} + P_a - G \tag{9}$$

From equations 5 and 9, matching the first terms of the relations, the relation to calculate the rolling force for one roll can be written:

$$F = \frac{\sigma_m \cdot \frac{\pi}{4}\left(D_s^2 - D_i^2\right)}{n \cdot \left(\mu - tg\,\frac{\alpha}{2}\right)\cos\frac{\alpha}{2}} \tag{10}$$

2. Simulation

2.1. Geometries and materials

The geometries of the billet, the active roll and the stem were generated in "Solid Works" and the meshes within their space domains in "Forge 2009". Fig. 6 shows the initial meshes of the billet and the tooling in cross section. For saving the computer RAM source and computation time [6] in the FEM analyses was carried out on 1/46 section from billet, stem and 1/2 section from one active roll.

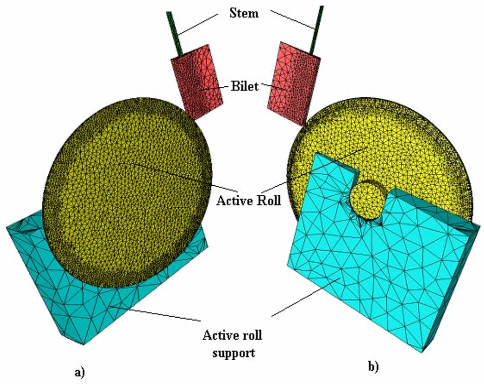


Fig. 6. *Sections trough the press rolling process: a) back view b) front view*

The puncher (stem) and the support were considered as perfectly rigid tools (for this tool is not necessary to define the material). The work piece material is Al99% and roll material is steel DIN 1.7350 X210Cr12.

2.2. Simulation parameters

Process parameters are presented in the following Table 1. The initial work piece, the tools and the environment temperature were considered 20°C. The stem speed during the process is 10mm/s. The coefficient of the friction at the interface active roll-work piece and stem-work piece is 0.7 and friction coefficient at interface active roll-support was chosen 0.1 (dry friction).

Table 1. *Simulation process parameters*

Billet length [mm]	30
Billet diameter [mm]	38….41
Billet temperature [^{o}C]	20
Tooling temperature [^{o}C]	20
Friction factor at interface billet-active roll	0.7
Friction factor at interface active roll - holder	0.1

Also, the heat transfer coefficient between tool-work piece and air been incorporated in finite element analysis.

4. Results and discussions

The graphs shape rolling force (obtained by simulations) is similar to the pressing force (Fig. 7).

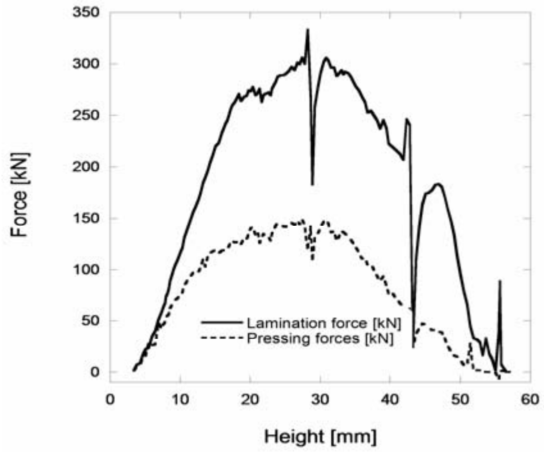


Fig. 7. *Graphics of forces obtained by simulation of rolling force and pressing force*

In the study of the press force evolution we can find three main phases (zones) specific to the evolution of the work piece during the rolling process:

1. entry zone:
   - adjustment roll zone (just for open bearing);
   - work piece clamping zone;
2. pseudo stationary flow zone,
3. exit zone:
   - step 1 - this zone begin when the ma material start to flow in reverse direction of rolling;
   - step 2
     - level a) - the force necessary to deform the material in rolling directions decreases and the force necessary for deform the material how flow in reverse direction is increased;
     - level b) - where the force decreases to zero, the negative value of the force jump (point P) corresponding to the action of part weight cumulating with the part velocity.

All these zones are described in Fig. 8.

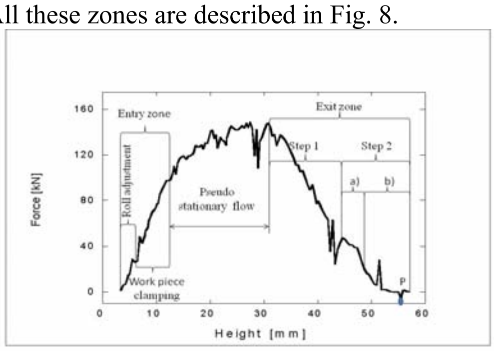


Fig. 8. *Phases of pressing force evolution in press-rolling process*

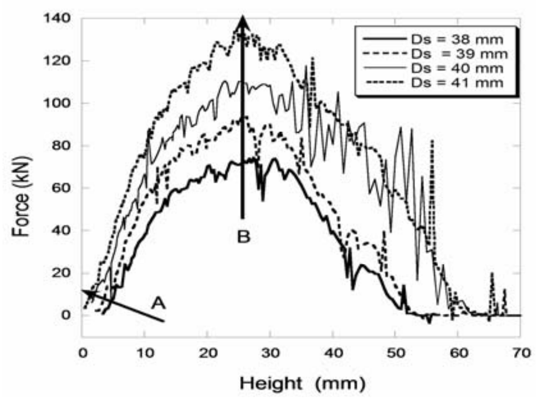


Fig. 9. *Pressing force evolution and punching stroke according to the initial work piece diameter*

The following comparative study of the evolution of the pressing force required for the pressing-rolling process and considering the process input variable initial work piece diameter (Ds).

Thus the initial work piece diameter directly influences the press-rolling process as shown in Fig. 9.

- arrow A in Fig. 9 indicates that the pressing force increases with the increase of the work piece diameter;

- arrow B in Fig. 9 indicates that the increasing diameter changes the parameters of the deformation area (increase grip angle, length of contact arc, while achieving a more complete filling of the outbreak strain exactly the gear tooth) while increasing the punching required course.

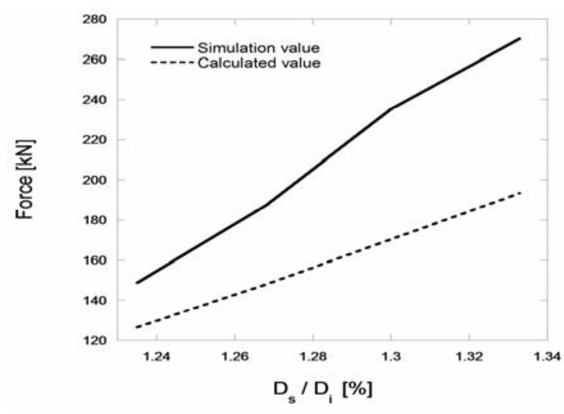


Fig. 10. *Pressing force evolution*

Comparing the pressing force obtained by numerical modeling of the process using FEM with results obtained using the analytical model we can draw the graph presented in Fig. 10.

Consequently, one can say that the graph of force calculated analytically calculated force closely follows the numerical chart. Calculation errors are largely due to the simplifying assumptions considered in theoretical relationships pressing force.

5. Conclusions

Process necessary force is greater than that calculated using mathematical relations, it is because the work piece sectional area changes its input in the process (between the punch and focus discharge work piece deformation occurs). Work piece diameter with increasing pressing force initially increases and travel needed punching process. The pressure is directly influenced by the weight of work piece.

Acknowledgment

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