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MATERIAL FLOW KINEMATICS DURING OSCILLATORY DIE FORMING

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Abstract: *During cold forming process, the use of an oscillatory motion die brings economic advantages because ensures higher worked piece deformation degrees, even when equipment installed power is smaller than in the conventional one case. The frontal contact surface between tool and worked piece is floating and represents only a part from the whole one. The paper studies material flowing mechanism in cases of pieces having different shapes and these processes dynamics.*

Key words: *oscillatory die, orbital volumetric forming, floating contact.*

1. INTRODUCTION

Unconventional volumetric forming process, when using an oscillatory die, presents a growing interest because it allows forming pressure controlling depending on worked piece geometry.

Forming pressure concentration on a restricted zone of worked piece frontal surface allows conducting deformation process into preferential directions, together to 5…20 times reduction of force required from the equipment and to maximum deformation degree, during a single working phase, increase.

The contact surface between oscillatory die and worked piece is floating and covers, during a functioning cycle, the whole worked piece frontal surface.

2. ORBITAL VOLUMETRIC FORMING PROCESS KINEMATICS

The force necessary to initiate the forming process is depending on the degree of reducing the contact surface between oscillatory die and worked piece. In Fig. 1 driving mechanism structure to gives an orbital motion to the forming die is shown, in principle.

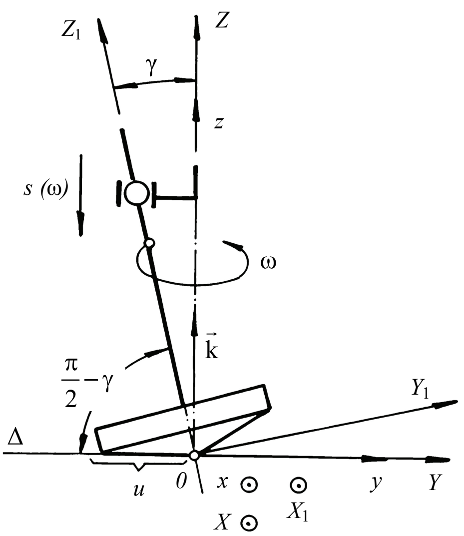


Fig. 1. Oscillatory die kinematics.

The dependence between superior die translation speed and its rotation around worked piece axis can be expressed as

$$v = \frac{\omega \cdot t \cdot s}{2\pi}, \tag{1}$$

where s means technological feed [mm/rot].

To study oscillatory die orbital motion, the following reference systems have to be defined:

- xyz, representing a fix system, attached to the worked piece;
- XYZ – mobile system, attached to the crank arm;
- $X_1Y_1Z_1$ – mobile system, attached to the forming tool.

Forming tool straight generating line is defined as

$$(\Delta)\ \left| \begin{array}{l} X_d = 0 \\ Y_d = -u \cdot \cos\gamma \\ Z_d = u \cdot \sin\gamma \end{array} \right. . \tag{2}$$

Under these conditions, the equations that describe forming tool surface result in the form:

$$X_1 = \omega_3^{\mathrm{T}}(v) \cdot X_d. \tag{3}$$

where $\omega_3(v)$ means rotation motion around OZ_1 axis matrix and has the form:

$$\omega_3(v) \begin{Vmatrix} \cos v & \sin v & 0 \\ -\sin v & \cos v & 0 \\ 0 & 0 & 1 \end{Vmatrix}. \tag{4}$$

After calculus it results:

$$\Sigma\ \left| \begin{array}{l} X_1 = u \cdot \sin v \cdot \cos\gamma \\ Y_1 = -u \cdot \cos v \cdot \cos\gamma \\ Z_1 = u \cdot \sin\gamma \end{array} \right. . \tag{5}$$

By considering process kinematics, the following equation can be written:

$$x = \omega_3^T(\varphi) \cdot \Gamma \cdot X_1 + S(\varphi) \cdot \vec{k}. \tag{6}$$

where

$$S(\varphi) = s \cdot \frac{\varphi}{2\pi} \tag{7}$$

and Γ means coordinates transformation matrix,

$$\Gamma = \begin{Vmatrix} 1 & 0 & 0 \\ 0 & \cos\gamma & \sin\gamma \\ 0 & -\sin\gamma & \cos\gamma \end{Vmatrix}. \tag{8}$$

After calculus, from (6) results:

$$\begin{vmatrix} x = X_1 \cdot \cos\varphi - Y_1 \cdot \sin\varphi \cdot \cos\gamma - Z_1 \cdot \sin\varphi \cdot \sin\gamma \\ y = X_1 \cdot \sin\varphi + Y_1 \cdot \cos\varphi \cdot \cos\gamma - Z_1 \cdot \cos\varphi \cdot \sin\gamma \\ z = -Y_1 \cdot \sin\gamma + Z_1 \cdot \cos\gamma - S(\varphi) \end{vmatrix}. \tag{9}$$

To find forming tool stamp shape and magnitude on the worked piece, the surface given through equations (9) will be sectioned by plains normal to feed direction,

$$z = -H. \tag{10}$$

By substituting z from (9) into (10), results, as it follows,

$$v = v(u), \tag{11}$$

which, together to the expressions of x and y from (9), define the stamp border curve.

To obtain pieces with wedge sections (conical rings from clutches or tapered roller bearings, tapered gears etc.) by extrusion is very difficult, because of very high friction forces that are acting on die lateral walls.

3. MATERIAL FLOWING PROCESS DURING ORBITAL VOLUMETRIC FORMING

In the case of conventional volumetric forming (Fig. 2a), as consequence to friction forces between dies active surfaces (inferior, superior) and worked piece, formed material will have higher flowing speeds into the median zone, which will generate barrel type errors of cylindrical shape.

When volumetric forming of cylindrical or ring shape pieces is done by using an oscillatory die (Figs. 2b and 2c), because of superior die rolling motion onto worked piece frontal surface, the material from superior zone will have a more intense flow into lateral direction than the material which is in contact with inferior die.

Thus, the piece will present conical type errors of cylindrical shape. If technological equipment includes a closed type of inferior die, dimensional and shape errors will be very small. In the case of an axial extrusion process (Fig. 3a), material cold hardening accelerates into the bottom zone. The difficulties amplify because of the high friction forces values acting contrary to material flow.

As consequence, to continue the forming process it is necessary to increase the deformation force. Under more convenient conditions, wedge-type piece can be obtained by flatting between two dies which are cyclic going closer / further on a direction normal to worked piece axis (Fig. 3b). Forming process develops gradually, because of tools consecutive motions. Contact loosing between dies and worked piece, which takes place during every cycle, gives to the last one a periodic advance motion. Roller bearings tapered roles manufacturing by flatting can be done by using a press having an orbital motion die (Fig. 4). The superior die axis, 1, has a precession motion when referring to inferior die, 2, axis; the angle between the two intersecting axis is γ.

The contact surface between oscillatory die and worked piece is reduced to 15–20% from total frontal ring surface and deforming force F is applied only to this fraction.

Between the punch 3 and the inferior die there is a controlled clearance, having a small magnitude. Thus, it will have a radial displacement under worked piece material pressure. Under these conditions, extrusion process is replaced by a radial and circumferential pressing one.

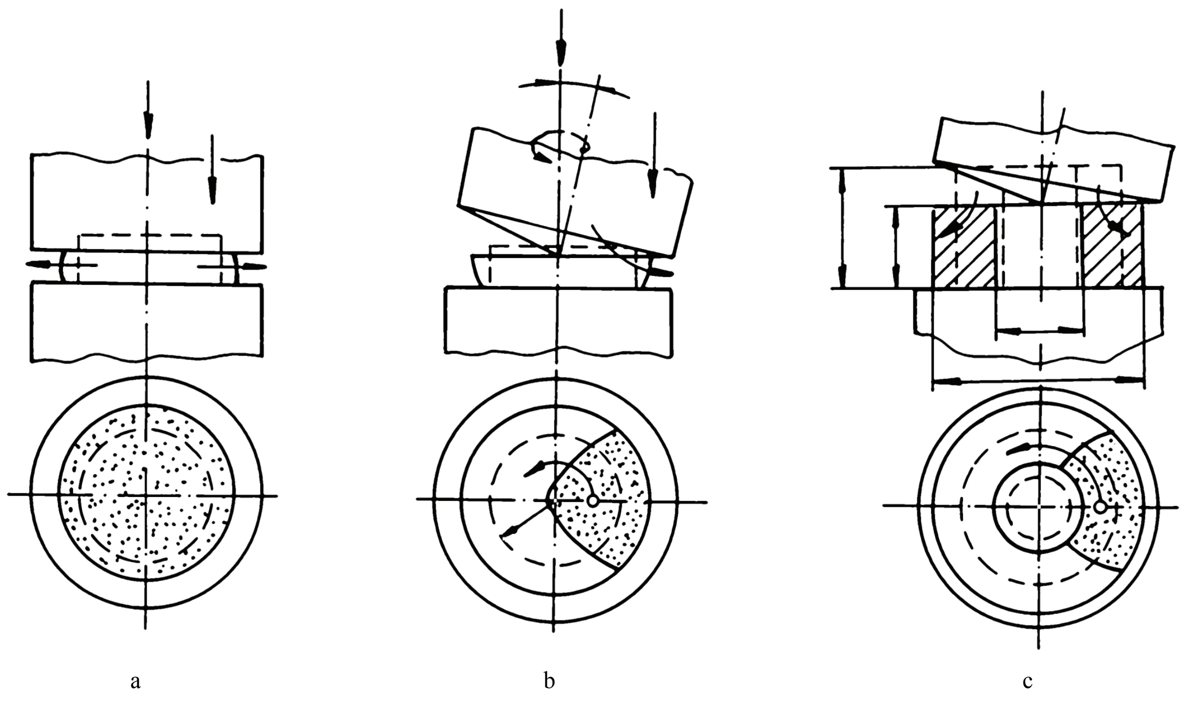
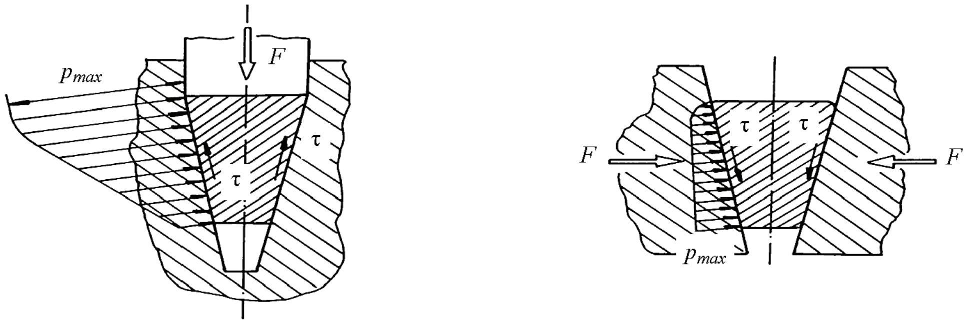
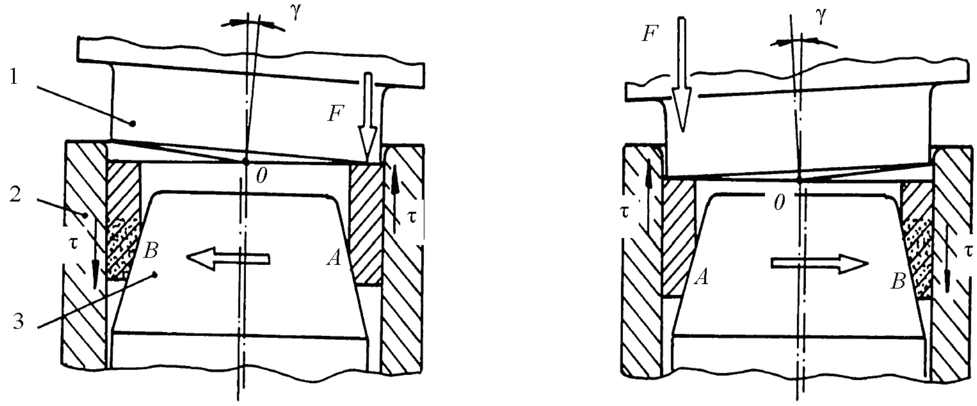


Fig. 2. Material flowing during volumetric forming: a – conventional pressing of cylindrical pieces; b – full cylindrical pieces cold forming by using an oscillatory die; c – cylindrical ring type pieces cold forming by using an oscillatory die.



a b

Fig. 3. Wedge type pieces manufacturing by forming: a – direct extrusion; b – cyclic flatting.



a b

Fig. 4. Material flowing mechanism during volumetric pressing of tapered rings by using an oscillatory die: *a* – central punch, *3*, oscillates to the left; *b* – idem, to the right.

4. TENSIONS AND DEFORMATIONS CONDITIONS ANALYSIS

In the zone *A* (Fig. 4) worked piece material is submitted to deforming force *F*, which generates a tri-axial compression pressure condition. This is defined by main stresses σ_1, σ_2 and σ_3. In the zone *B*, diametrical opposed, axial stress σ_3 is zero. Tangential stress σ_{1B} is quite equal to the one from *A* point, to ensure worked piece mechanical equilibrium.

Conform to those shown in Fig. 5, from punch 3 equilibrium condition, radial tensions from both zones equality results.

Stresses condition is characterized through following equations:

$$\sigma_{1\mathrm{A}} < 0; \quad \sigma_{2A} < 0; \quad \sigma_{3A} < 0, \tag{12}$$

$$\sigma_{1B} \approx \sigma_{1A}; \quad \sigma_{1A} < \sigma_{1A}; \quad \sigma_{1A} = 0. \tag{13}$$

Flowing condition will be:

$$2\sigma_c^2 = (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2, \tag{14}$$

where σ_c means flowing limit stress.

Thus, in the zone *A* the material is displaced like a rigid body, while in the zone *B* material suffers a plastic deformation, causing a ring wall thinning. During orbital forming process, diametrical opposite zones pair *A* and *B* will circumferential migrate on ring type worked piece frontal surface. Floating punch forming process is similar to rolling process.

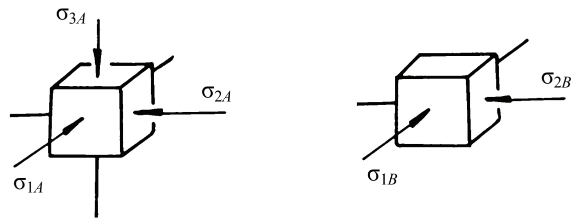


Fig. 5. Stresses conditions in zones *A* and *B*.

When manufacturing pieces by conventional pressing the die exerts to their surface a unitary pressure which must increase in time to avoid material cold hardening effects, together to friction between the surfaces in relative motion effect.

Complementary to these technologies, orbital forming process kinematics allows pieces manufacturing on equipments developing forces smaller by a number of times than the conventional ones and, as consequence, productions costs are more reduced.

During forming processes that use an oscillatory die, superior die – worked piece momentary contact zone is characterized by a wide focus. In this case, additional stretching stresses appear which may lead even to a material breaking.

By analyzing this deformation process, analogical to rings rolling, in order to simplify material flowing methodology of study, we further consider that the process is characterized by a plain stresses condition.

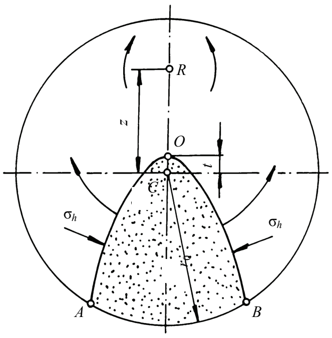


Fig. 6. Material flowing mechanism during orbital volumetric forming.

Conform to dedicated publications, outside the main deformation zone a secondary zone, named "plastic rocker pin" appears (Fig. 6).

If accepting that lateral stress σ_h is uniform distributed to *AOB* arc length, which is delimitating forming focus from the rest of the worked piece, we may consider that this arc comports like a thin plate articulated in *O* point.

During the process, a radial flowing zone, *AOB*, appears and thus, the frontiers *AO* and BO are extending, by pivoting around so-called rocker pin, *R*.

Due to the resistance opposed by adjacent zones, and also due to friction to the oscillatory die, material radial flowing is relative reduced compared to its circumferential pivoting around plastic rocker pin.

Material tendency to move around *R* point generates σ_h stress, which leads to deformation normal stress increasing. To evaluate this stress magnitude, we accept that plastic rocker pin position (*z* distance) is, conform to dedicated literature, the solution of the equation

$$z^2 + z \cdot t + z - 1 = 0. \tag{15}$$

where *t* means the distance between contact zone bottom and worked piece centre.

Same time, to calculate σ_h lateral stress; the following relation can be used:

$$\sigma_h = \sigma_c \frac{hr_o}{2}\left[\left(1-\frac{z}{r_o}\right)^2+\left(\frac{t}{r_o}+\frac{z}{r_o}\right)^2\right], \tag{16}$$

where *h* means worked piece thickness in the deformation zone.

When *t* takes values between 0 and 0.2, we may observe that σ_h has a variation between $(0.23\ldots0.33)\sigma_c$ and, currently, we appreciate that $\sigma_h \approx 0.3\sigma_c$. By σ_c the flowing stress during mono-axial volumetric forming was denominated.

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