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FRICTIONAL FORCE VECTOR REVERSAL AT METAL DRAWING WITH ULTRASONIC ACTIVATION OF THE TOOL

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1. Introduction

The main characteristic of the drawing technologic processes, which essentially differentiates them among other plastic manufacturing procedures based on metal pressing, consists in the fact that the magnitude of the technologic deformation achieved in one pass (during a single stage) depends on the maximum value of the stress which acts on the cross section of the intermediate product, when it exits from the deformation focus.

In other words, the cross section reduction per a pass directly dependens on the work hardening capacity of the material being processed.

Also, it is necessary for the magnitude of the drawing stress acting on the intermediate product to be lower than the tensile strength. This condition is expressed by means of the so called safety coefficient of drawing [1, 2]:

$$c_{st} = \frac{S_1 \cdot \sigma_r}{F_t} \quad , \tag{1}$$

where S_1 is the cross-sectional area of the intermediate product, when it exits from the deformation focus zone; σ_r is the tensile strength of the obtained product (including the work hardening acquired within the drawing process); F_t is the drawing force.

In the case of the technologic drawing processes of metals with ultrasonic actuation of the tool oriented parallel with the drawing direction, the average drawing force reduction is obtained due to the "surface effect of ultrasonics" caused by the frictional force vector reversal at the metal-tool contact during the time $T/2\text{-}2t_1$ within one complete oscillation period, when v_{tr}/v_v, < 1 (v_{tr} is the drawing rate and v_v is the oscillation rate of the tool) [3].

2. Frictional force vector reversal at metal drawing with ultrasonic activation of the tool

The paper approaches the possibility to reduce the average drawing force due to the frictional force vector reversal, when technologies involve free drawing for obtaining wires, rods (Fig. 1,*a*) and tubes (Fig. 1,*b*) as well as for tube drawing on a plug (Fig. 1,*c*).

The frictional force vector reversal, that is the orientation of the vector of the average frictional force along the metal displacement direction, is obtained only in the case, when both the plastic deformation focus is located in the oscillation maximum of the waves and activation is performed parallel with the drawing direction, providing $v_{tr}/v_v < 1$ (Fig. 2) [4].

Activation is accomplished within the ultrasonic range (for frequencies higher than l6 Khz [5]) and is stimulated by longitudinal elastic waves. Thus, in fact, the kinematics of plastic deformation at drawing is characterized by the displacement of a material point A', arbitrarily chosen within the deformation focus area at the metal-tool contact (see Fig. 1,*a* and *b*).

The point A' on the metal-tool contact surface takes part in two motions:
(i) a feed motion with the rate v_a along the generatrix of the cone of the tool plastic deformation and (ii) an oscillation motion with the rate v_v, which vector forms the angle β with the slope α of the cone generatrix.

Assuming that oscillations are produced according to the motion law:

$$u = a \cdot \sin \omega t_1 \tag{2}$$

the oscillation rate of the material point A' is determined as a time derivative of the motion equation:

$$v_v = du/dt = A\omega\cos\omega t_1 \tag{3}$$

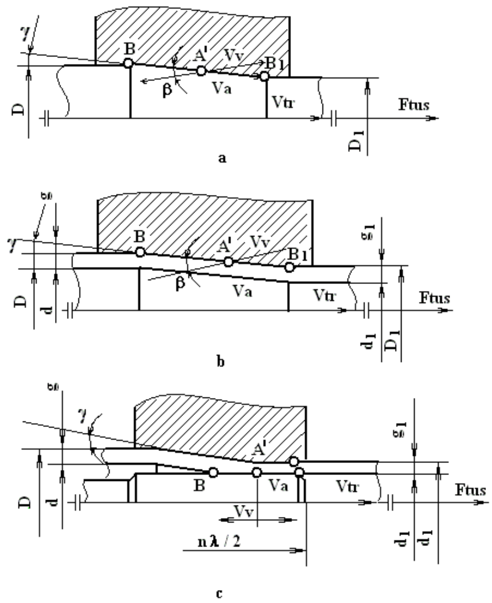

Figure 1.

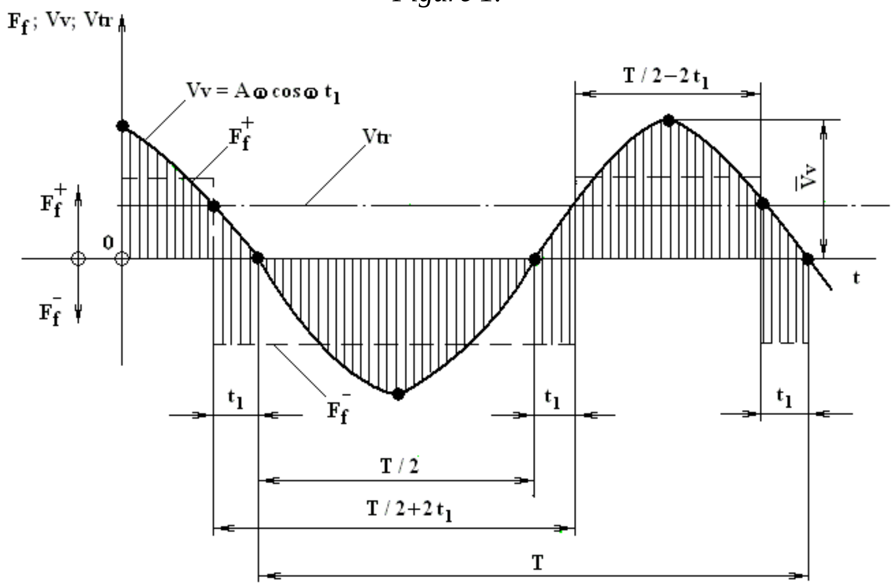

Figure 2.

The maximum oscillation rate (v_v) is reached, when $\omega t_1 = 1$:

$$\bar{v}_v = A \cdot \omega = 2\pi f \cdot A \tag{4}$$

where *A* is the oscillation amplitude and f is the resonance frequency of the oscillating system.

In technologic processes involving the plastic deformation by drawing, for small angles α, it is possible to approximate $v_{tr} \approx v_v$.

The resulting vector of the relative rate alters the direction of motion of the point A'. Namely, during the time $T/2\text{-}2t_1$ in the oscillation period the displacement of the point A'. will be in the same direction as that of the metal, when the projection of the oscillation rate vector (v_v) is larger than that of the drawing rate vector along the B - BI direction. The reverese situation is observed during the time range $T/2+2t_1$, when the ratio of magniutudes of the named vectors' projections reverses along the same direction.

In other words, during the time $/2\text{-}2t_1$ in the oscillation period the frictional force is positive (F_f^+) and during the time $T/2+2t_1$ the frictional force is negative (F_f^-). The ratio [4]:

$$\varphi = \frac{(T/2 + 2t_1) + (T/2 - 2t_1)}{(T/2 + 2t_1) - (T/2 - 2t_1)} \tag{5}$$

represents the reduction degree of the average force in the considered point (A ') at the metal-tool contact. From the equality for the two rates (for oscillation and for drawing), the following expression for t_1 is derived.

$$t_1 = \frac{1}{\omega} \arccos \frac{v_{tr}}{v_v \cdot \cos\beta} \qquad (6)$$

Substituting the values for t_1 and T in relationship (5) we obtain:

$$\varphi = \frac{\pi}{2} \cdot \frac{1}{\arccos \dfrac{v_{tr}}{v_v \cdot \cos\beta}} \qquad (7)$$

If the average value for the drawing rate is taken into account (according to the continuity equation of the metal flow), the reduction degree of the frictional average force (coefficient φ) upon the whole metal-tool contact surface is obtained for the enter-exit cross sections from the deformation area:

$$\varphi = \frac{\pi}{2} : \arccos \frac{v_{tr} \dfrac{\lambda_i \cos\alpha + 1}{2\lambda_i \cos\lambda}}{\overline{v}_v \cdot \cos\beta} \qquad (8)$$

or an approximate value :

$$\varphi = \frac{\pi}{2} \cdot \frac{\overline{v}_v}{v_{tr}} \cdot \frac{2\lambda_i \cdot \cos\lambda}{\lambda_i \cdot \cos\lambda + 1} \cdot \cos\beta \ , \qquad (9)$$

where λ_i is the strain coefficient per one pass, $\lambda_i = (D/D_1)^2$ for wires and rods with a round cross-section and

$$\lambda_i = D_{med.i-1} \cdot g_{i-1} / D_{med.i} \cdot g_{i-1}$$

for tubes, here $D_{med} = (D+d)/2$ and $g = (D-d)/2$ [1].

The relationship (7) gives evidence that the greater is the reduction of the average frictional force (expressed by means of the coefficient φ), in the case when v_{tr} = ct., the lower is the angle β, which defines the actuation direction of the tool, or in other words the greater are both the oscillation frequency and the amplitude.

Thus, in the case of the new drawing technologies with ultrasonic activation of the tool (see Fig. 1,*a* and *b*), it is recommended that the angle β equals 0°, that is the activation to be parallel the drawing direction (Fig. 1,*c*).

The tube drawing on a plug with ultraacoustic activation (Fig. 1,*c*), is considered to be the only procedure which is applied at the industrial level in order to obtain tubes of resistive to cold drawing metals. The procedure is also known under the name of "Sonodraw ", applied for the first time in the USA by researches from "Aeroproject" Inc. of the West Chester Pa. [6, 7].

The reduction of the average frictional force, at the metal-plug contact, is also due to the frictional force vector reversal, when $v_{tr}/v_v < 1$ (see Fig. 2), and the length of both the rod and the plug may be expressed as $n \cdot \lambda/2$(λ is the wave length; $\lambda = c/f$, where c represents the rate of wave propagation and f is the resonance frequency, *n* is integer 1,2,3...).

The simplified relationship of Gavrilenko is considered for force determination in the case of drawing plastic deformation processes [4]:

$$F_t = F_d + F_f = F_d(1 + \mu ctg\alpha) , \qquad (10)$$

where F_d is the actual deformation force, F_f is the frictional force, μ is the coefficient of friction and α is the generatrix slope.

In the case of drawing processes with the ultrasonic activation of the tool, equation (10) becomes:

$$F_{tus} = F_d \left(1 + \frac{\mu ctg\alpha}{\varphi}\right) \qquad (11)$$

that is, the frictional force is reduced divided by the coefficient φ.

The efficiency of the new plastic deformation technologies by means of the ultrasonic actuation of the tool is expressed by the relationship [8]:

$$\Delta F = \frac{F_t - F_{tus}}{F_t} \cdot 100\,\% \cdot \qquad (12)$$

For special situations of drawing plastic deformation, in the case of the new technologies for obtaining tubes, rods and wires, it is possible to predict an average frictional force reduction, based on relationship (12). To make this, the optimum values for the ratio v_{tr}/v_v are adopted, on which the coefficient φ magnitude depends

In Fig. 3 the variation of coefficient φ (relationship 9) is presented as a function of the ratio v_{tr}/v_v under the conditions: β = 0°; α = 12°; *f* = 18000 Hz and λ_i = 1,27 [3].

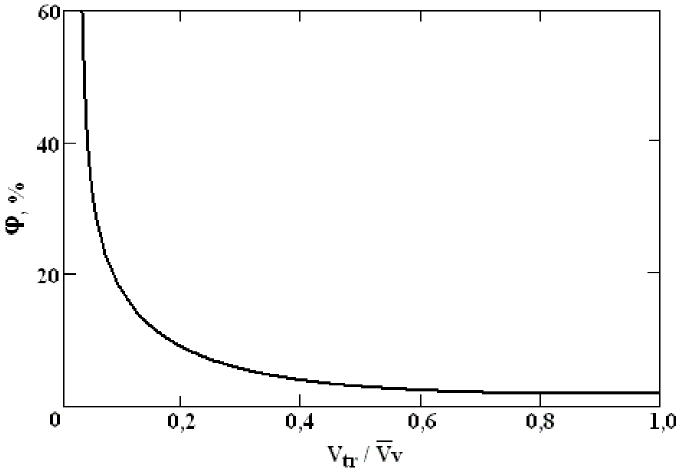

Figure 3.

For the high efficiency of the utlrasonic energy in the drawing plastic deformation processes the use of ultrasonic energy reflectors is recommended [4].

3. Conclusions

The paper presents the main features of the frictional force vector reversal in the processes of plastic deformation of metals and in technologies for obtaining tubes, rods and wires, when the tool is located in the oscillation maximum of the waves actuated parallel to the drawing direction.

The frictional force becomes positiv during $T/2\text{-}2t_1$, when $v_{tr}/v_v < 1$, and negative during $T/2+2t_1$, when $v_{tr}/v_v > 1$, within one complete oscillation period.

The plastic deformation of metal occurs under condition $v_{tr}/v_v > 1$, when, in fact, there are no difference as compared to classic drawing process.

This fact emphasises the fractionated (pulse) character of plastic deformation during a complete oscillation period, which also explains the average frictional force reduction, because for $v_{tr}/v_v < 1$ the metal-tool contact does not exist.

The situation characterised by $v_{tr} = v_v$ is not technologically allowed, because the influence of the ultrasound energy is negligible in the plastic deformation processes, if to take into account that the upper limit of drawing rate is defined as a function of the oscillation rate of the tool [4, 6, 7]

The above-mentioned facts justify the use of the ultrasonic energy in the drawing technologies of resistive to cold drawing metals for wich $v_{tr}/v_v < 1$.

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Summary

The paper presents the possibility to reduce the average drawing force in the technologies for obtaining tubes, rods and wires, when the tool is located in the oscillation maximum of the ultrasonic waves and actuated parallel to the drawing direction. This reduction is explained by the frictional force vector reversal during the time $T/2\text{-}2t_1$ within a complete oscillation period, when $v_{tr}/v_v<1$. This fact justifies the use of ultrasonic energy in the plastic deformation processes of resistive to cold drawing metals.