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Production of billets of die-rolled section when vibratory drawing

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Abstract
The results of the analysis of energy-power parameters of die-rolled sections production by vibratory drawing considering kinematic parameters of process are presented. Technological process and vibratory drawing device with a cyclic support when using of the self-turned-out piston as an elastic support were developed.

Key words: VIBRATORY DRAWING, CYCLIC SUPPORT, DIE-ROLLED SECTION, SHAPING, INERT FORCES, SELF-TURNED-OUT PISTON

Production of billets of die-rolled section under stamping of turbine blade from hardly deformed nickel and titanic is extremely urgent and perspective. Conventional technology of billets production for blades stamping, for example, made of heat-resistant nickel alloy ZHSBKP of bars with a diameter of 40-50 mm comprises hot rolling by a few dozen passes with intermediate heating. Pieces of smaller diameter turbine blades get cutting treatment on lathes. However, coefficient of metal usage according to this technology does not exceed 0.05-0.14 [1-3].

Products with variable cross section can be obtained by shaping and stretching in the conditions of superplasticity. The main advantages of the process are associated with large deformation ability of superplastic materials, non-contact conditions of deformation and high resistance of shaping processes. These products are obtained under the condition that one of the velocities defining the kinematics of the processing is constant, and another is changed according to a given program. The method is effective in small-scale production with a wide range of products [4-5]. Commercial development of this process is constrained by the lack of knowledge about the shaping and kinematics of the deformation zone, as well as its low performance.

In general, to obtain billets with periodic profile made of nickel and titanium alloys is an independent task in the general problem of improving blade production technology (one-lock, two-lock blades).

The effectiveness and feasibility of industrial application of drawing process using sonic and ultrasonic frequency ranges of oscillations have been proved by works of many researchers. The intermittent nature when the vibration of the deformation tool or treated metal leads to a number of positive factors intensifying processes of metalworking.

For certain schemes and modes of vibration deformation (in particular, when vibratory drawing), the effect of periodic change of the wire or rod diameter along its axis was observed. On the one hand, it can be seen as a negative factor leading to a distortion of the geometry of the resulting item. On the other hand, this opens the possibility for obtaining wire and rods with periodically repeating sections. In any case, at negative or positive assessment of this factor, this process needs to be managed and its laws should be known. Perhaps this phenomenon can be explained by the analysis of the following phenomena.

1. The implementation of the conditions under which one of the velocities determining the kinematics of the process is constant and the other varies according to a given law. Periodic workpiece profile was first obtained when vibratory drawing with longitudinal vibrations of the die [2], at a certain vibrations frequency. However, there is a whole arsenal of methods to change one of the velocities when the vibratory drawing: connection of vibrations to drawing die or treated metal, which are directed across or around (rotational) of drawing axis and angular ones. Also a combination of transverse vibrations with longitudinal ones, drawing with a cyclic support, drawing with pulsating counterstrain, step, two-step vibratory drawing, drawing through the two dies vibrating in opposite phases, three-stage vibratory drawing, drawing through a system of multiple dies loaded in turn finds its application.

2. Frictional self-excited vibrations. Under the conditions of the friction of solid bodies at a constant or intermittent draft force, the harshness of sliding was

observed and it was accompanied by a more or less periodic stops. Possible explanations of slip instability are associated with the presence of a falling-speed characteristic of the friction force or the emergence of the so-called “jump” ΔT of the friction force in the transition from rest to sliding. At each jump, the rise of amplitude of normally asymmetric oscillations occurs resulting in compression of a deformable material. This type of oscillation in a vibratory drawing is a violation of the law of motion of the vibrating tool and, as a consequence, frequency of not only microgeometry but also geometry of workpieces under treatment. To evaluate the nature of this phenomenon is possible by solving the problem of elastic-plastic deformation during vibratory drawing with setting the appropriate boundary conditions associated with the law of friction, which takes into account the friction self-oscillations.

3. Loss of stability of deformable system. In the process of shaping, there are four types of deformable metal plastic stability [3, 4]: slip bands, centered thinning, secondary slip bands, undulations.

When leaving the deformation zone in the process of vibratory drawing a die-rolled section of the workpiece may occur at local thinning and stretching during the formation of undulation. Loss of stability nature occurs under the scheme other than Euler. The ratio of the deforming load P and the characteristic movement U is expressed concave downward curve. This P - U dependency is observed under tension conditions. The ascending part of the curve corresponds to sustainable forms of equilibrium. At the maximum point, the load takes a stationary value remaining constant at infinitely small changes U corresponding to adjacent forms of equilibrium. The system state at the maximum point is critical, and the corresponding values $P = Pcr$ and $U = Ucr$ are critical load and displacement. The critical load Pct coincides with the maximum carrying load of the system $Pmax$. Under such a load, the local loss of stability in the form of local thinning is possible. The problem of the stability of elastic-plastic deformation is solved by studying the motion of the system near equilibrium. A condition under which small disturbances provokes movement deducing system from the vicinity of the equilibrium state is instable. To assess the critical deformation in which the process of plastic strain of bar, rod or wire becomes unstable is possible in the following way. Let us consider rod stretching by force $P(t) = P_0 sin(w\ t\text{-}A)$. In turn, $P(t) = \sigma F$, where σ normal stress in a cross section of the bar, F – the cross-sectional area.

When the condition (1) the neck journal is formed.

$$dP = \left(\frac{d\sigma_{11}}{d\varepsilon} d\varepsilon + \frac{d\sigma_{11}}{d\dot{\varepsilon}} d\dot{\varepsilon} + \frac{d\sigma}{dt} dt \right) F + \frac{\sigma_{11} dF}{d\varepsilon} d\varepsilon \langle 0 \,, \tag{1}$$

For deformable bar, various close states are possible, for which the decrease in the cross section is compensated by the increase of stress due to hardening. However, the material of the deformable system (bar) has some irregularities, the so-called "weak spots" as geometric and structural nature. "Neck" is formed and rapidly developed due to local deviations from the correct shape and inhomogeneities conditions in one of the spots. When transforming the equation (1), we obtain the condition of unstable deformation:

$$\frac{d\sigma_{11}}{d\varepsilon} = \frac{\sigma_{11}}{(1+\varepsilon)} \tag{2}$$

For the material which is hardened according to a power law, the rheological properties are described by the following ratio $\sigma = c\varepsilon^n \dot{\varepsilon}^m$, where $\dot{\varepsilon} = \frac{d\varepsilon_1}{dt} = \frac{d(\ln \ell)}{dt}$ - deformation rate of the bar elongation. When $m = 0$, the material does not have viscous properties $\varepsilon_{cr} = \frac{n}{1-n}$, where ε_{cr} – critical deformation.

Formation of periodic profile occurs out of the deformation zone under the influence, on the one hand, of the constant pulling force, on the other hand, of cycling support with counterstrain during vibration of dies. Under these conditions, when the workpiece is subjected to tensile and compressive loads, the conditions of unstable equilibrium occur after reaching the maximum (critical) load. For a quantitative description and the study of non-equilibrium, unstable processes [7], it is possible to use equilibrium approach to show the plasticity within the thermodynamic and total system approaches [8]. To assess the degree of deformation of the workpiece at the exit from the deformation zone, the changes of the surface area of the deformable workpiece were efficiently used. Application of the workpiece surface as a deformation criterion relates to the fact that the surface is generally one of the major defects of the crystal structure [9] and it is associated with forming of the additional workpiece surface.

4. Impact of inert forces.

When vibratory drawing with a sufficiently high rate, the significant role is played by inertial forces, emerging and propagating of waves in the metal, the localization of the plastic deformation, etc. The latter factor may lead to destabilization of the transverse dimensions of the obtained product. The equations of motion and incompressible will be of the following form:

$$div\overline{\upsilon} = 0; \tag{3}$$

$$\frac{\partial}{\partial x_i}\left[\frac{T(\upsilon_i)}{H(\upsilon_i)}\left(\frac{\partial \upsilon_i}{\partial x_k}+\frac{\partial \upsilon_k}{\partial x_i}\right)+\delta_{ik}\sigma_0\right]+\rho F_i=\rho\frac{d\upsilon_i}{dt} \; . \tag{4}$$

It is possible to consider the drawing process in one-dimension when the equations of motion acquire the simplest form:

$$\rho\left(\frac{\partial \upsilon_1}{\partial t}+\upsilon_1\frac{\partial \upsilon_1}{\partial x_1}\right)=\frac{\partial \sigma_0}{\partial x_1}+\frac{4}{3}\frac{\partial}{\partial x_1}\left(\frac{T(\upsilon_1)}{H(\upsilon_1)}\frac{\partial \upsilon_1}{\partial x_1}\right) \; . \tag{5}$$

For a perfect plastic material in the absence of convection, this equation can be written as follows:

$$\rho\frac{\partial \upsilon_1}{\partial t}=\frac{\partial \sigma_1}{\partial x_1}, \tag{6}$$

Taking into account that deformations are low, i.e. $\frac{\partial U}{\partial x_1} < 1$, so $\frac{\partial \upsilon_1}{\partial t}=\frac{\partial^2 U}{\partial t^2}$. As:

$$\frac{\partial \sigma_1}{\partial x_1}=\frac{\partial \sigma_1}{\partial \varepsilon_1}\frac{\partial \varepsilon_1}{\partial x_1}=\frac{\partial \sigma_1}{\partial \varepsilon_1}\frac{\partial}{\partial x_1}\left(\frac{\partial U}{\partial x_1}\right)=\frac{\partial \sigma_1}{\partial \varepsilon_1}\frac{\partial^2 U}{\partial x_1^2}, \tag{7}$$

we obtain wave equation:

$$\frac{\partial^2 U}{\partial t^2}=\frac{1}{\rho^2}\frac{d\sigma_1}{d\varepsilon_1}\frac{\partial^2 U}{\partial x_1^2}, \tag{8}$$

where ρ - density of the material of the deformable system.

In equation (8) $\frac{d\sigma_{11}}{d\varepsilon_1}=\mathrm{var}$ it is necessary to use special methods of its solution and analysis of the results obtained. Let us consider the solution variant at the assumption of the validity of the hypothesis of "flat diametrical cross sections" that fits into the framework sufficient for engineering calculation methods. The elementary energy required to change the speed of some infinitely small mass of the material dm in the deformation zone is equal to the momentum of the weight applied to the force:

$$dF\cdot dt=d\dot{U}\cdot dm. \tag{9}$$

Taking into account the predominantly axial flow of deformable material, we replace differentials of speed, time and weight by their values:

$$dm=\rho F d\ell, \tag{10}$$

$$d\dot{U}=V_0\frac{d\ell}{\ell}, \tag{11}$$

$$dt=\frac{d\ell}{V_0}, \tag{12}$$

where V_0 – drawing speed.

After transformation we will obtain:

$$dF=\rho V_0^2 F\frac{d\ell}{\ell}. \tag{13}$$

Equation (1) takes the form:

$$d(\mathrm{P}\pm F)=\sigma_{11}dF+Fd\sigma_{11}=0, \tag{14}$$

When $$d\sigma_{11}=\frac{\partial \sigma_{11}}{\partial \varepsilon_{11}}d\varepsilon+\frac{\partial \sigma_{11}}{\partial \dot{\varepsilon}_{11}}d\dot{\varepsilon}_{11}+\frac{\partial \sigma_{11}}{\partial t}dt. \tag{15}$$

The required condition takes the form:

$$\frac{1}{\sigma_{11}}\left(\frac{\partial \sigma_{11}}{\partial \varepsilon}d\varepsilon+\frac{\partial \sigma_{11}}{\partial \dot{\varepsilon}}d\dot{\varepsilon}+\frac{\partial \sigma_{11}}{\partial t}dt\right)=\frac{d\varepsilon}{1+\varepsilon} \; . \tag{16}$$

At the law of strain-speed hardening, we get:

$$n\varepsilon^{n-1}\varepsilon^{m}d\varepsilon+m\varepsilon^{n}\varepsilon^{m-1}d\dot{\varepsilon}+\frac{\partial}{\partial t}\left(\varepsilon^{n}\dot{\varepsilon}^{m}\right)dt=\frac{\varepsilon^{n}\dot{\varepsilon}^{m}d\varepsilon}{1+\varepsilon} \tag{17}$$

For a material with a low-speed hardening m ≈ 0, we get to the differential equation of the following form:

$$nd\varepsilon+nd\dot{\varepsilon}=\frac{\varepsilon d\varepsilon}{1+\varepsilon}\cdot \tag{18}$$

Thinning on the sample appears in the following ratio of deformation and its speed:

$$\dot{\varepsilon}(t)=\dot{\varepsilon}(0)\left[\varepsilon(n-1)-\ln(1+\varepsilon)\right]\cdot \tag{19}$$

By analogy, for viscous materials with low strain hardening n = 0, we obtain:

$$\dot{\varepsilon}(t)=\dot{\varepsilon}(0)(1+\varepsilon)^{\frac{1}{2m}}\ . \tag{20}$$

Thus, the conditions for sustainable shaping are provided when the obtained ratio of kinematic parameters of drawing.

5. The bilateral compression of the workpiece element at the outlet of the deformation zone

Drawing cylinder of a die prevents radial flow of the workpiece material, which is similar to the action of external friction forces in the sinking strain of cylindrical workpieces. Compression of the workpiece element at the outlet of the die may be provided by applying an elastic support. The latter may be performed in an annular container 3 with deformable walls filled with fluid under pressure Fig.1. [2]

It is more preferably to carry out the elastic support as a self-turned-out piston Fig. 2.

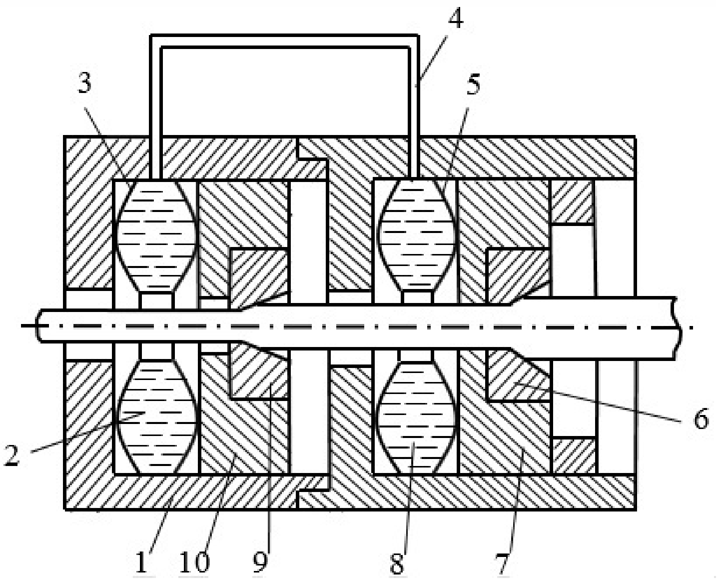

Figure 1. Self-oscillatory hydromechanical devices for metal drawing: 1 - body frame; 2, 8 - liquid; 3, 5 - container with elastic annular walls; 4 - the connecting channel; 6, 9 - dies; 7, 10 – die plates

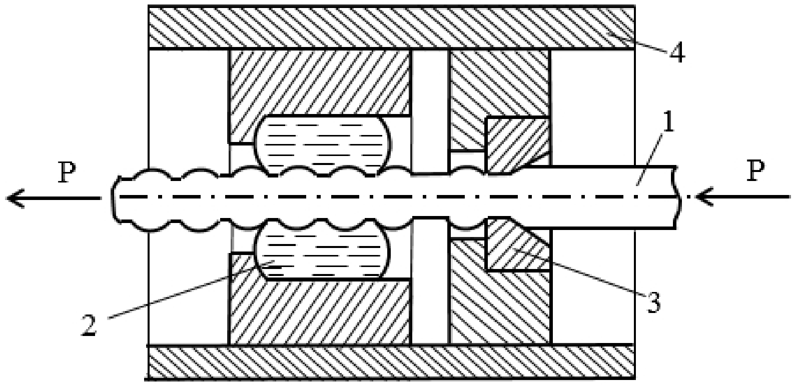

Figure 2. Vibratory drawing with cyclic support when being used as elastic support of self-turned-out piston: 1 - blank; 2 - self-turned-out piston; 3 – die; 4 - die plate

In accordance with the principle of Saint-Venant, the action radial forces attenuates with distance from the contact surfaces. Therefore, when bilateral compression of blanks, the linear stress state scheme occurs in the middle of the length of the compressed blank element.

Conclusions

1. The effect of the periodic variation of the diameter of bar or wire when vibratory drawing is connected with friction vibrations, loss of stability during the deformation as at occurring of a yield stresses in the bar material, and at the formation of a "neck", as well as the result of inert forces.

2. The obtained dependences allow us to determine the conditions of the unstable strain and stabilize the process of obtaining a periodic profile by controlling the process parameters of vibratory drawing.

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