APPLICATION OF THE HYBRID CONTROLLER FOR ISOTHERMAL EXTRUSION PROCESS CONTROL

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Abstract. Nowadays most of critical machine elements are manufactured by means of extrusion method. Such workpieces are widely applicable in aeronautical and rocket engineering as well as transport mechanical engineering. One of the methods allowing workpiece quality improvement is isothermal extrusion which provides constant temperature on the surface of the workpiece by changing extrusion velocity. To control over isothermal extrusion process was designed hybrid intelligent controller. This controller was realized as neuro-fuzzy system.

1. INTRODUCTION

In the whole world large-sized products from light and special-property alloys in order to meet the needs of aeronautic, space, shipbuilding, energetic and transport engineering are produced on high-powered horizontal and vertical hydraulic presses (of 100...750 MN force), which are the part of forging and press complexes. The examples are as follows: computerized production line of long-length large-sized products like compound cross-section panels of 1.5 m wide and 35 m long, made of high-strength aluminum alloys on the basis of horizontal presses of 120 and 200 MN force; automated unit on the basis of vertical presses of 300 and 750 MN force for die forging irregular shaped articles of light and special steels with an area of 8000 cm2; automated unit on the basis of hydraulic press of 300 MN force using the method of hydrostatic stretching for production of steel shroud rings with a diameter of 2.5 m necessary for hardening of winding front parts of large unit rating turbo generators for nuclear power stations.

It is a well-known fact that the most high-powered horizontal and vertical hydraulic presses, of 200 and 750 MN force correspondingly, are exploited in Russia. For instance they are used to produce large-sized structural components for wide-body aircrafts Boeing-777 and A-380 by orders of Boeing and Airbus companies.

The general disadvantage of high-powered forging and press complexes is their insufficient data ware (including the stage of technological processes design) and low-level control systems. It can be explained by the fact that the technological processes realized on the high-powered hydraulic presses are characterized by factors variety, nonlinear links between process parameters, instability, big delays in control channels, unregulated noises and perturbations, great number of feedback couplings, stochasticity of major technological processes parameters and other factors. All the above mentioned impedes the processes design and makes it impossible to realize both linear control systems, which don't reflect the real systems characteristics, and use of compound nonlinear mathematical models, which precisely reflect the physical correlation between systems input and output but are absolutely useless for process control in the real time.

There are two major ways to make high-powered forging and press complexes more intelligent: 1) development of design expert systems of irregular shaped articles plastic deformation technological processes and 2) creation of intelligent technological machines and complexes' control systems by modernizing the existing ones.

2. BASIC MATHEMATICAL MODEL OF ISOTHERMAL EXTRUSION

Basic mathematical model of isothermal extrusion was made on the ground of complex mathematical model.

Dependence of temperature of metal on the exit from die from the basic technological parameters can be described
by functional dependence

$$\vartheta(t) = \varphi\left(t,\ X,\ V(t),\ \delta(t)\right) \qquad (1)$$

where t is time, X is array of basic technological parameters (geometrical size of tools, initial temperature of tools and billet, thermophisical and mechanical properties of tools and billet), $V(t)$ ram velocity and $\delta(t)$ are unsuspected parameters.

With ram velocity of different constant values, function Eq. 1 can be written in form

$$\vartheta(t) = \vartheta_{st} - \left(\vartheta_{st} - \vartheta_{b}\right)\left(\frac{\varepsilon_1}{\vartheta_{st} - \vartheta_{b}}\right)^{\frac{t}{t_{st}}}, \qquad (2)$$

where ϑ_{st} temperature of workpiece surface on the steady process stage with constant velocity V, ϑ_b initial temperature of a billet, t_{st} is time taken to reach steady temperature mode and ε_1 is a small quantity which is predefined by accuracy of temperature sensor (doesn't exceeds 1.5% of upper limit of a measured value).

The base velocity mode of isothermal extrusion is defined as the function where ram velocity is dependant on distance $V=V(s)$ or time $V=V(t)$. This functional dependence provides temperature constancy on the surface of the workpiece which leaves the die.

The algorithm for calculating base velocity modes was created on the basis of the complex mathematical model. Full distance of ram moving was divided into finite number of control stage. On every stage the initial (for the stage) extrusion velocity V_i and a number of time steps are set. The problem of calculating base velocity mode for isothermal extrusion is set in the following form: to find a sequence
of velocity values which provides a difference between the temperature of isothermal extrusion $\tilde{\vartheta}$ and workpiece surface temperature less then ε in the end of each control stage. Here ε is a small quantity which is defined by technological consideration and accuracy of temperature sensor.

For practical use in automatic control system, base velocity modes were approximated by formula

$$V(t,\ X)=\begin{cases} V_i, & t<t_i,\\ V_{st}+\left(V_i-V_{st}\right)\left(\dfrac{\varepsilon_2}{V_i-V_{st}}\right)^{\frac{t-t_1}{t_{st}^{*}-t_i}}, & t\ge t_i. \end{cases} \tag{3}$$

In this formula V_i and V_{st} are velocities of ram in the be-ginning of the process and in the steady stage, ti is the time during which the velocity Vi is sustained, t^*_{st} is time taken to reach steady velocity mode and ε_2 is a small quantity which is defined by accuracy of extrusion velocity sensor (doesn't exceeds 1% of upper limit of measurement).

3. HYBRID CONTROLLER FOR ISOTHERMAL EXTRUSION PROCESS

The intelligent control system of the extrusion process provides isothermal extrusion conditions by speed regulation of compression ram in the extrusion process (Fig. 1).

In this system intelligent control is used in hybrid controller which connects a neural networks and fuzzy logic technology.

The authors created a model of such hybrid system. In the book Gotlib and Dobychin (1985), the process of pipes isothermal extrusion out of D16 aluminum alloy by 58,8 MN force press is considered. For technological reasons all types of pipes were divided into three groups according to the geometrical sizes of matrix and a needle. Basic technological parameters of the process have the following values: diameter of container D_c=370 mm, temperature of isothermal extrusion $\tilde{\vartheta}$=470ºC, the initial temperature of the billet ϑ_b and container ϑ_c were changed from 350 to 450ºC, the ram velocity was changed from 2.0 to 8.0 mm/s.

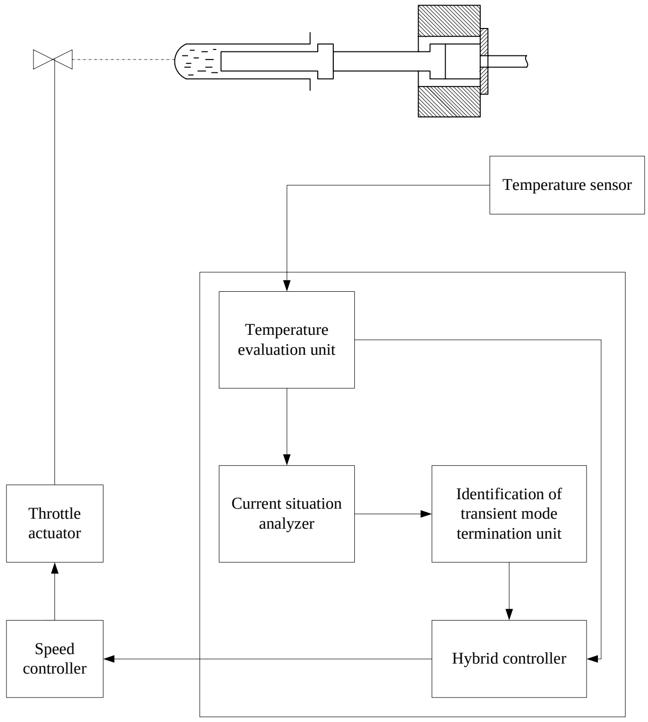

Fig. 1. Intelligent control system of isothermal extrusion

To simplify further use of dataset the following regression equations were obtained:

a) for values 101.5≤D_m≤126.5 and 51≤D_n≤96.5

$$\begin{aligned}
\vartheta_{st} &= 93.38+1.907D_m+3.493D_n+0.1936\vartheta_b+0.06013\vartheta_c+\\
&\quad 32.72V-0.03678D_mD_n+0.01605D_n^2-0.3104D_nV,\\
t_{st} &= -2400+24.43D_m-0.9481D_n+7.735\vartheta_b-0.3048\vartheta_c-\\
&\quad 13.56V-0.06785D_m\vartheta_b\\
V_{st} &= 5.749+0.06876D_m-0.03813D_n-\\
&\quad 0.01267\vartheta_b-0.00791\vartheta_c,\\
V_i &= 6.139+0.08066D_m-0.0361D_n-0.01367\vartheta_b,\\
t^*_{st} &= 316.9+1.858D_m-0.8678D_n-0.3885\vartheta_b-0.3829\vartheta_c;
\end{aligned} \tag{4}$$

b) for values 126≤D_m≤157 and 60.5≤D_n≤122.3

$$\begin{aligned}
\vartheta_{st} &= 313.2+0.5543D_m+0.05255D_n+0.2719\vartheta_b+\\
&\quad 0.05753\vartheta_c+6.525V-0.01429D_mD_n+0.01271D_n^2,\\
t_{st} &= -600.1+0.4338D_m-0.2658D_n+2.313\vartheta_b+\\
&\quad 1.816\vartheta_c-12.13V-0.005654\vartheta_b\vartheta_c,\\
V_{st} &= -5.805+0.0642D_m+0.11D_n-0.00657\vartheta_b-\\
&\quad 0.0007522D_n^2,\\
V_i &= 6.113+0.09873D_m-0.05395D_n-0.01616\vartheta_c,\\
t^*_{st} &= 388-0.5497D_n-0.2733\vartheta_b-0.2731\vartheta_c;
\end{aligned} \tag{5}$$

c) for values 151.2≤D_m≤172 and 91≤D_n≤146.5

$$\vartheta_{st} = -359 + 9.278D_m - 0.8466D_n + 0.244\vartheta_b + 0.05463\vartheta_c + $$
$$+16.25V - 0.0303D_m^2 + 0.00544D_n^2 - 0.0965V^2,$$
$$t_{st} = -3799 + 22.84D_m 3.331D_n + 9.78\vartheta_b - 0.3344\vartheta_c + \\ 104.5V - 0.06056D_m\vartheta_b - 0.9389D_nV,$$
$$V_{st} = -18.06 + 0.0791D_m + 0.2534D_n - 0.009262\vartheta_b - \\ 0.001206D_n^2, \quad (6)$$
$$V_i = 617.7 - 4.903D_m - 0.6265D_n - 0.4781\vartheta_b - 0.4767\vartheta_c + $$
$$+0.01539D_m^2 + 0.002417D_n^2 + 0.00064\vartheta_b^2 + 0.00063\vartheta_c^2$$
$$t_{st}^* = 812.7 - 1.807D_n - 0.365\vartheta_b - 0.7845\vartheta_c .$$

In these formulas diameters of matrix (D_m) and needle (D_n) are given in millimeters.

At the first stage of hybrid system we use three neural networks (one for each of three groups). These networks are used to calculate of parameters ϑ_{st}, t_{st}, V_{st}, V_i, t^*_{st} which are included in the basic isothermal extrusion model. These parameters are defined by Eq. 4-6. In this case fully-connected three-layered feed-forward backpropagation neural networks type are used.

At the second stage of hybrid system we use methods of fuzzy sets theory. As all groups have partial intersection of their initial parameters, for this reason membership function for each group was created. As a membership function we use trapezoid functions of two variables. Using a values of membership functions and outputs of neural networks we calculate the final values of parameters ϑ_{st}, t_{st}, V_{st}, V_i, t^*_{st} to obtain the temperature of metal and base velocity mode with Eq. 2 and Eq. 3.

Such system architecture gives an opportunity for the most exact approximation of all necessary parameters. Structural scheme of hybrid controller of isothermal extrusion is on Fig. 2.

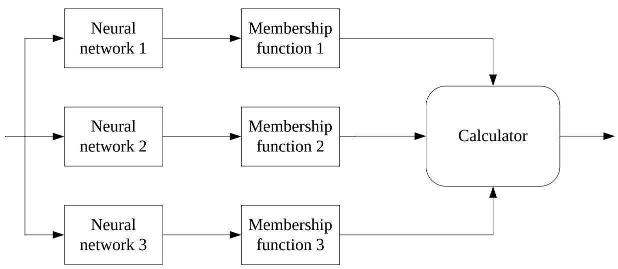

Fig. 2. Structural scheme of hybrid controller of isothermal extrusion

It's obvious that the suggested structure controller can be used for different methods of isothermal extrusion and die forging. Also different alloys workpieces can be manufa-ctured.

4. CONCLUSION

Using such system architecture we achieve the system control goals at most and implement the model of the process that is grounded on the knowledge base in the real time control process.

REFERENCES

1. **Gotlib B. M., Dobychin I. A.** (1985), Adaptivnoe upravlenie processami obrabotki metallov davleniem, *Metallurgiya*, USSR.
2. **Gotlib B. M., Byvalzev S. V.**, **Tarasyan V. S.** (2006), Tendencii i problemy intellektualizacii mogshnyh kuznechno-pressovyh kompleksov, *Proceedings of 3rd Scientific Conference «Mechatronics, automatic, control»: 1st Russian Multiconference for control problems*, LETI, SPb, Russia, 317-320.