Quality estimation of the technology process controlling system of making the glass rods

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Abstract. The article considers the transition process of controlling the drawing of glass rods (Light guide). To solve that problem the static and dynamic features of the object have been considered. The process of drawing the light guide is being made by adjusting the speed of the output link of the drawing machine. The paper considers the driven glass movement in the light guide formation zone and determines the transition process pattern, in a system: “Controlling machine – formation zone”. The time of the transition process is being estimated.

1. Introduction
Fiber – optic elements have a huge application area. The object of research – technological process of drawing optical core from softened glass. It is made by drawing softened glass mass through spinneret or by pulling from billet with its edge softened in an oven. Light guide solid geometry depends on many factors. The role of instalments vibration on disturbance formation is sufficient. Vibration of units, which linked with a drawing light guide, may cause oscillation of drawing speed. Vibration, while transits through a drawing light guide to the formation zone, might influence on the formation process of the light guide and hence on its quality. It is important to consider kinematic and dynamic drawing parameters, caused by random disturbances and necessary to adjust the process [1, 2].

Identification of the controlling object’s features relates with solving the following problems: mathematical model of the process; exploration of the transitional processes linked with an output to the settled regime. The sensitivity of the formation zone to deviations of basic technological parameters was determined. This will let us determine the accuracy of that parameters maintenance on the input level and normalize the disturbance’s level according to the requirements of the drawing light guides quality [3, 4].

2. Types of control
In the direct control the cross-sectional geometry measured drained product (rod diameter, its roundness and the like). Typically, the adjustment is performed by changing the pulling rate. For indirect control parameter is measured, which depends on the geometry of the rod. Such parameters may be as follows: the value of the rod tension (stretching force) or the geometric shape of lightguide forming zone.
3. Choosing the controlling scheme
Using any controlling scheme, the determination of the object’s dynamic features is required. These features are being determined by the dependence of input value on output value in a transition regime. A lot of schemes appear depending on what controlling parameters are chosen (output values) and control actions (input values).

While interaction of ACC (automatic controlling system) and drawing instalment, vector of input actions $\vec{u}(t)$ from controlling machine applying on ACC (Fig.1). Output signals vector $\vec{x}(t)$ effects on drawing instalment’s characteristics, and disturbing actions vector $\vec{f}(t)$ effects on ACC’s characteristics. Signal $\vec{y}(t)$ goes on ACC and on controlling machine from dimension system [5, 6, 7].

There are two schemes for considering process: light guide diameter control – controlling the drawing speed; light guide power control - controlling the drawing speed.

4. Dynamic model and its mathematic description
While making a dynamic model it is necessary to count the dynamic characteristics influence of functionally linked interacting systems. Wielding the process of light guide drawing happens when adjusting a drawing machine’s output unit speed. Controlling machine may be presented as a scheme (Fig. 2) electric engine 1 is linked with outdrawing machine 2; $\phi_e$, $\phi$ - input and output parameters respectively.

There are electric engines of constant current, which have a linear mechanic characteristic used in electric drives.

The dynamic characteristic of that engine looks like:
\[ \tau \frac{dM}{dt} + M = M_S, \]

where \( \tau \) – electromagnetic constant of engine time; \( M_S \) – static engine’s characteristic.

Value \( \tau \) determines the inertia of electromagnetic processes occurring in the engine and in its control system. The changes of magnetic field in an anchors chain and in the controlling system will happen a little bit later in comparison with disturbances changes. (\( U \) or \( \omega \)).

Drawing mechanism equation in differential form:
\[ J \frac{d\omega}{dt} + \frac{1}{2} d \frac{dJ}{d\varphi} \omega^2 = M - M_c, \]

where \( J \) – the given moment of inertia; \( \omega = \frac{d\varphi}{dt} \) – the angular velocity of the output link of the drive mechanism (actuating unit), \( M_c \) – reduced moment resistance forces.

Thus, there is mathematic model presenting the dynamic model of drawing instalment:
\[ \tau \tau_m \frac{d^2\omega}{dt^2} + \tau_m \frac{d\omega}{dt} + \omega = \frac{1}{k} \left( M_0 - M_c - \tau \frac{dM_c}{dt} \right), \]

where \( \tau_m = 1/k \) – drawing instalment’s time constant in general.

The equation of output link’s angular velocity changing in a drawing machine is:
\[ \frac{d^2\omega}{d\psi^2} + 2 \zeta \frac{d\omega}{d\psi} + \omega = \omega_2, \]

where \( \psi = t / \sqrt{\tau_m \tau}, \ \zeta = 0.5 \sqrt{\tau_m / \tau}; \ \omega_2 \) – angular velocity, to which the mechanism goes after application of the controlling signal on the engine.

5. Nature of transitional processes

Transition process character in a drawing instalment depends on the relation of the values: constant instalment time and constant engine time (\( \zeta \)). For \( \zeta > 1 \): drawing machine is a deadbeat unit, for \( \zeta < 1 \) drawing machine is an oscillatory unit.

Record the characteristic equation of the link as
\[ \lambda^2 + 2 \zeta \lambda + 1 = 0, \]

the roots will be \( \lambda_{1,2} = -\zeta \pm \sqrt{\zeta^2 - 1} \).

Considering the way of transitional process for \( \zeta > 1 \).

The solution becomes:
\[ \omega = \omega_2 + A_1 \exp(\lambda_1 \psi) + A_2 \exp(\lambda_2 \psi), \]

where \( A_1, A_2 \) – constant dependants from the initial conditions.

Supposing that \( \omega = \omega_1 \ \psi = 0 \), it is possible to obtain
\[ \omega_1 - \omega_2 = A_1 + A_2, \ \frac{\omega_2 - \omega_1}{2\zeta} = A_1 \lambda_1 + A_2 \lambda_2. \]

After the transformations, \( A_1 \) and \( A_2 \) are found:
\[ A_1 = \frac{\Delta}{2\zeta} \cdot \frac{2\zeta^2 \lambda_2 + 1}{\lambda_1 - \lambda_2}, \quad A_2 = \frac{\Delta}{2\zeta} \cdot \frac{2\zeta^2 \lambda_1 + 1}{\lambda_2 - \lambda_1}, \]

where \( \Delta = \omega_2 - \omega_1 \) – диапазон регулирования скорости \( \omega \).

Considering (3) as

\[ \frac{\Delta_\omega}{\Delta} = 1 + \bar{A}_1 \exp(\lambda_1 \psi) + \bar{A}_2 \exp(\lambda_2 \psi), \]

where \( \bar{A}_1 = A_1 / \Delta \); \( \bar{A}_2 = A_2 / \Delta \); \( \Delta_\omega = \omega - \omega_1 \).

There are transitional process graphs in figure 3 for \( \zeta = 2 \) (curve 1) and \( \zeta = 0.5 \) (curve 2). Transitional process for \( \zeta = 0.5 \) has a fading oscillations character.

\[
\begin{align*}
\Delta_\omega / \Delta \quad &\quad \Psi \\
1 \quad &\quad 2 \\
0 \quad &\quad 5 \\
&\quad 10
\end{align*}
\]

**Figure 3.** Transients in the installation drawing.

Observing the transitional process character for \( \zeta < 1 \) in that case the equation’s (2) solution is going to be

\[ \omega = \omega_2 + A_3 \exp(-\zeta \psi) \cos\left(\sqrt{1 - \zeta^2} \psi + \alpha\right), \]

where \( A_3, \alpha \) – constants which are determined by initial conditions.

Using the initial conditions, obtaining

\[ \frac{\Delta_\omega}{\Delta} = 1 + \bar{A}_3 \exp(-\zeta \psi) \cos\left(\sqrt{1 - \zeta^2} \psi + \alpha\right), \]

where \( \bar{A}_3 = -\frac{1}{2\zeta \sqrt{1 - \zeta^2}} \).

Analysis of the expression (5) shows, that in this case a transitional process transits with an aligning and has a fading oscillations character.

Transitional process’s character allows us to choose the way of controlling. During deadbeat character of transitional process (without alignments), it is necessarily to use a forced transition method from \( \omega_1 \) to \( \omega_2 \).

If the transitional process had an oscillation character (with alignments), quasi optimal controlling could be applied to decrease the transitional process duration (figure 4).
Figure 4. Quasi optimal methods of regulation of the engine speed.

The stress, applied for the engines anchor, is being changed rapidly. At the initial moment $\psi_0$ the stress is applied relating on speed $\omega'_1$.

For $\psi = \psi_1$ angular velocity reaches its peak, hence $\frac{d \omega}{d \psi} = 0$.

For $\psi > \psi_1$ the process has settled, $\omega = \text{const} = \omega_2$.

Transient processes in the drive create a perturbing force acting on the ongoing technological process (drawing of products, shaping during machining, etc.). (A zone of product formation).

That power changes the same way as the rod drawing velocity (angular velocity of a driven unit)

$$F(t) = \Delta F \Omega,$$

where $\Delta F = F_2 - F_1$; $F_1, F_2$ – the magnitude of the pulling forces of the rod corresponding to the velocities $\omega_1, \omega_2$; $\Omega = \Delta / \Delta_\omega$; $\Delta_\omega = \omega - \omega_1$.

To evaluate the behavior of molten glass introduced dimensionless parameters $n, \tau, T$. Glass mass in an oscillatory zone and reveals elastic features. Transitional processes character in a system “Light guide formation zone – drawing installation” depends on sequent values: $\zeta, n, \tau / T$.

Transitional processes character for different combinations $\zeta, n$ provided in a table 1.

Table 1. Transitional processes character for different combinations $\zeta, n$.

| System parameters | Transitional regimes character          |
|-------------------|----------------------------------------|
| $\zeta > 1, n > 1$ | Deadbeat                               |
| $\zeta < 1, n > 1$ | Deadbeat and oscillatory               |
| $\zeta > 1, n < 1$ | Deadbeat                               |
| $\zeta < 1, n < 1$ | Oscillatory (with alignment)            |
6. Managing quality estimation

Stability linked with system behaviour in an infinity, when the real systems work on an exact time range. System is considered as satisfied to a required quality if the transitional characteristic stays within a zone of allowed deviations. Transitional process’s time is one of the direct features of the system’s quality.

The expressions, obtained above, defining the character of transitional processes, allow to make a calculation algorithm for the all considered cases [6, 10, 11].

If there is a necessity of regime change, the voltage applies on the electric engine, which is appropriate for the velocity $\omega_3$, which is bigger than the one necessary for the velocity $\omega_2$. Then $\omega$ increases forcibly. For $\psi_1$, when $\omega$ reaches the required value $\omega_2$, the voltage needs to be decreased by the power surge to the value, appropriate for the velocity $\omega_2$.

The difference $\psi_1 - \psi_0 = \psi_{nm}$ defines transitional process time. With $n$ increasing, the value $\psi_{nm}$ increases, but with $\tau_u/T$ increasing, it decreases.

The managing object parameters, at first $\tau$, have a huge impact on the transitional process time, which defines the managing quality. Obtained, that for $\tau \to \infty$ the transitional process time gets stabilized, approaching the edge limit.

7. Conclusions

Mathematical models of the control unit and the control object for the study of transient regimes that arise in process control are proposed. It should be noted that the internal elastic inertial vibration protection is particularly efficient for single-mode machines ensuring the imbalance growth. To implement the control circuitry, direct and indirect methods of measuring the geometrical characteristics (the diameter, the thickness of the walls of the capillary) of the light guide are used. On the basis of theoretical studies, directions for the future development of drawing devices have been determined, in accordance with which a number of schematic technical solutions have been proposed.

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