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The Problem of Modeling the Practice of Heat Treatment in the Preparation of Shafts of Technological Machines

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Abstract: In this article, the solution of the problem posed by the method of modeling the process of thermal processing is considered in solving the problems of managing and facilitating the technological process of manufacturing the shafts of technological machines and various techniques. As a result of theoretical studies, it was stated that the proposed thermal treatment model of shafts allows for rational control of the direction and amount of internal stresses in the preparation of shafts of technological machines and other techniques.

Keywords: Technological machine, technological process, thermal treatment (finding, release, normalization), modeling, control and facilitation issues, noble shaft, residual stresses and deformations.

INTRODUCTION

The reliability of technological machines in use is closely related to the reliable operation of their individual parts and details. Therefore, it is necessary to solve the issues of management and facilitation of factors and practice indicators that affect the process of preparation of shafts that are widely used in them.

In solving the problems of controlling and optimizing the technological process of manufacturing shafts, the above-mentioned problems are solved by modeling the practice of thermal treatment.

Research in the fields of metallurgy and thermal treatment has shown that the phase changes in the material are mainly determined by the maximum heating temperature, and the magnitude of internal stresses is determined by the time dependence of the heating and cooling temperatures. The state of stress under temperature influences is described by the equations of thermodynamics, thermoelasticity and thermoplasticity. However, the complexity and magnitude of the analytical expressions in this case, as well as the extreme sensitivity of the solution to fluctuations in thermodynamic constants, make it necessary to consider a more rational, more standardized method of statistical expression, which treats thermal treatment as a controlled object.

RESEARCH METHODS

Figure 1 shows the approximate dependence of temperature on time during thermal treatment.

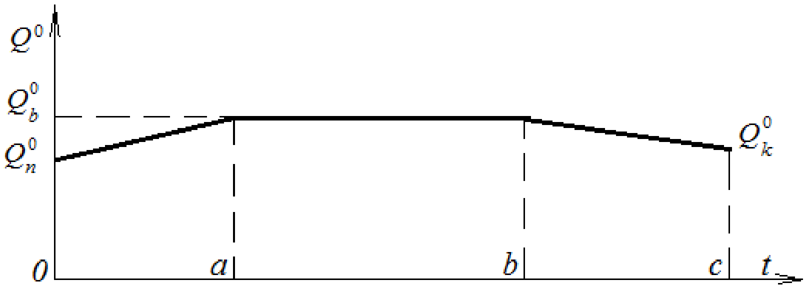

Figure 1. Dependence of temperature on time during heat treatment

In the figure, part *oa* is used to heat the part, part *ab* is used to hold it steady, and part bc is used to cool it. The general relationship is written as follows:

$$Q^{\circ}(t)=\begin{cases} Q_n^{\circ}+K_1\cdot t, & 0\le t<a, \\ Q_b^{\circ}, & a\le t<b, \\ \dfrac{Q_b^{\circ}-Q_k^{\circ}}{c-b}\cdot t-\dfrac{b\left(Q_b^{\circ}-Q_k^{\circ}\right)}{c-b}, & b\le t<c \end{cases} \qquad (1)$$

here K_1 – is the heating rate, $K_2=\left(Q_b-Q_k\right)/\left(c-b\right)$ - the cooling rate.

The cooling rate depends on the cooling conditions (water, oil, atmosphere, artificial ventilation, etc.).

Thermal processing equipment allows you to adjust the following parameters of the heating-cooling pair: K_1 – heating rate; Q_b - holding temperature (maximum heating temperature); K_2 – cooling rate; $\tau=b-a$ - holding time at the maximum temperature.

In thermal processing operations, when considering the technological system as a controlled object, its mathematical model is written in the form of vector equations in general:

$$\begin{aligned} &\overline{X}^{entry}=f\left(\overline{X}^{exit}\right), \\ &\overline{X}^{entry}=\left(L,\, d,\, \Delta_h,\, \sigma_{str.work.},\, K_1,\, K_2,\, Q_b,\, t\right), \qquad (2) \\ &\overline{X}^{exit}=\left(\Delta_{sh}, H\right), \end{aligned}$$

where L, d – length and diameter of the workpiece (L and d are variables, taking into account the heterogeneity of the parts); H – surface hardness after heat treatment; Δ_{sh} - shape error in the longitudinal section (caused by temperature deformations); Δ_h - hardness of the shaft axis deformation before heat treatment; $\sigma_{str.work.}$ – residual stresses in the workpiece.

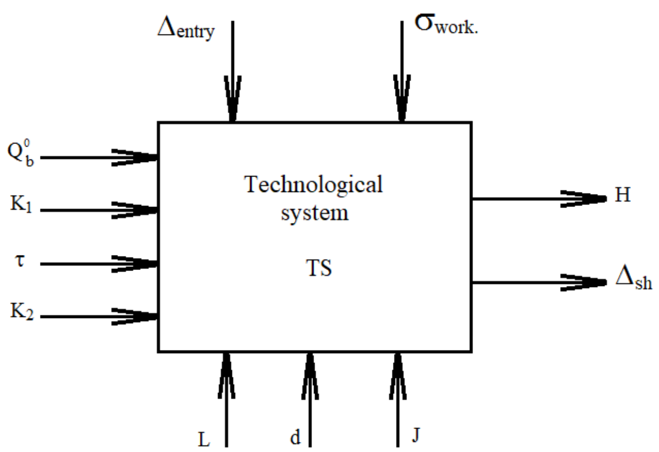

Figure 2. Scheme of the technological system of thermal treatment as a controlled object

The following model was obtained by the method of planning experiments using plan type 2^{6-3}:

$$\Delta_{sh} = \beta_0 \cdot K_1^{\beta_1} \cdot Q_b^{\beta_2} \cdot K_2^{\beta_3} \cdot \tau^{\beta_4} \cdot L^{\beta_5} \cdot d^{\beta_6} \quad (3)$$

Using the least squares method and regression analysis, the experimental data were modeled and all the coefficients β_0, β_1, β_2, ... β_n of the model were obtained.

Thermal processing of workpieces (heat treatment, annealing, normalization) occurs with a change in their stress state. The process of formation of residual stresses during cooling is characterized by three periods. In the initial period, thermal stresses are formed due to the difference in cooling of the outer and inner layers of the workpiece (part). Such stresses reach their maximum value at the largest temperature difference Q_0 that the workpiece (part) reaches over the cross section:

$$Q_0 = (Q_{start} - Q_{EE}) \cdot (Q_{surface\ work.} - Q_{center\ work.}) \quad (4)$$

where Q_{start} and Q_{EE} are the temperatures of the start of cooling of the workpiece and the external environment temperature, respectively; $Q_{surface\ work.}$ and $Q_{center\ work.}$ – temperatures of the workpiece surface and center, respectively.

As the temperature difference decreases, the stresses generated by the temperature also decrease, reaching zero at a certain point - then the workpiece is free from stresses. As cooling continues, due to the fact that the cooling rate of the center of the workpiece is greater than the cooling rate of its surface, characteristic stresses opposite to the previous stresses are formed, the value of which increases until the workpiece is completely cooled, after which these stresses remain in the workpiece: they have a compressive nature on the surface, and tensile in the center. A common cause of deformation of workpieces is uneven temperature deformations during heat treatment and deformations resulting from phase stresses. This situation occurs in materials that undergo phase changes during heat treatment. Types of thermal treatment such as tempering or tempering, which are used in practice after the workpiece is heated, regulate the structure of the material and significantly reduce phase stresses.

Due to the limited thermal conductivity of materials, cooling and temperature deformation occur simultaneously. At any given moment, each elementary part of the detail in the cross-section will have a relative deformation corresponding to the static equilibrium of the system in the instantaneous distribution of this temperature.

At any instant of time, the stresses directed along the residual axis in the elementary layer are determined by means of a certain equation [1]:

$$\sigma = E\left[\varphi_{y+k} - a_1 \cdot \varphi(y)\right], \quad (5)$$

here φ_{y+k} - the parameters of the overall neutral form; $\varphi(y)$ - function of temperature distribution on the section; a_1 – is a temperature-dependent coefficient.

In addition to axial stresses, radial and tangential stresses are also generated when cylindrical parts are cooled. In the limit of elastic deformations, the following equations are relevant:

$$\varepsilon_r = \frac{1}{E}\left[\sigma_r - \mu(\sigma_t + \sigma_{ax})\right],$$

$$\varepsilon_t = \frac{1}{E}\left[\sigma_t - \mu(\sigma_r + \sigma_{ax})\right],$$

$$\varepsilon_{ax} = \frac{1}{E}\left[\sigma_r - \mu(\sigma_r + \sigma_t)\right],$$

where ε_r, ε_t and ε_{ax} - are radial, tangential and axial residual deformations, respectively.

Radial and tangential residual stresses cause residual deformations that increase the crosssectional dimensions of the workpiece. Longitudinal deformations are determined by axial residual stresses. Axial residual stresses are determined by the following relationship over the cross-section of the workpiece [1, 2, 3, 4]:

$$\sigma_{ax} = \left(1 - \frac{3x^2}{2d^2}\right) \cdot \frac{\beta \cdot E \cdot Q_0}{3}, \qquad (6)$$

where β – is the temperature expansion coefficient. In this case, the longitudinal force created by the tensile stresses is determined from the following expression:

$$P_{ten.} = -\frac{2\beta \cdot E \cdot Q_0 \cdot d}{3}. \qquad (7)$$

βE=2,4 N/m^2·grad for steel; $Q_0 = \Delta Q \cdot K_3 \frac{\alpha_2}{\lambda_1} \cdot d$; K_3 – is proportionality coefficient and K_3 =0,35 for steel; α_2 – heat transfer coefficient; λ_1 – heat transfer coefficient; $\Delta Q = (Q_{start} - Q_{EE})$; $\Delta Q = (Q_{surface\ work.} - Q_{center\ work.})$.

Putting these into equation (7):

$$P_{ten} = 0{,}56\alpha_2 \cdot \Delta Q \cdot d / \lambda_1 \qquad (8)$$

The axial force P_{ten} is uniformly distributed over the workpiece cross-section. When calculating deformations, we assume that the workpiece enters the heat treatment with an initial shape error in the longitudinal section. The equation of the bent axis of the shaft before heat treatment is:

$$y = f_0 \cdot \sin\frac{\pi x}{L} \qquad (9)$$

where f_0 – is the value of the shaft deflection before thermal treatment; x – is the current coordinate.

When thermal treatment is applied, the shaft is deflected under the action of an axial force, and the equation of the deflected shaft axis is as follows:

$$M(x) = EI \cdot \frac{d^2 y}{dx^2}, \qquad (10)$$

where y – is the magnitude of the additional deformation of the shaft at the distance “x” from the coordinate origin after thermal treatment. The bending moment resulting from the axial force is defined as:

$$M(x) = P_{ten} \cdot \left(y + f_0 \cdot \sin\frac{\pi x}{L}\right). \qquad (11)$$

Taking into account equation (11) and the critical force determining the stability of the system $P_{cri} = \pi^2 EI / L^2$ (Euler's critical force), we solve equation (10), and we obtain the deformation of the shaft during thermal treatment:

$$f_{ther.} = \frac{f_0}{1 - \frac{P_{ten}}{P_{cri}}}. \qquad (12)$$

Using expression (8) P_{ten} and critical strength P_{cri}, we finally express the mathematical model of thermal treatment:

$$f_{ther.} = f_0\left(1+\frac{EI\cdot\lambda_1}{EI\cdot\lambda_1 - 0{,}56\cdot\Delta Q\cdot L^2\cdot d\cdot\alpha_2}\right) \quad (13)$$

CONCLUSIONS

The following conclusion can be drawn from the analysis of the obtained expressions and analytical studies:

- it is possible to determine the deformation of the details in the copy of the "shaft" at the stage of the development of the technological process and assign the appropriate minimum size of the deposit for processing. This reduces the consumption of metal, power, consumption of lubricating-cooling fluids;
- the proposed thermal treatment model allows for rational control of the direction and amount of internal stresses in the preparation of shafts of technological machines and other equipment.

REFERENCES

1. Драчев О.И., Тараненко В.А., Шаабидов Ш.А., Мартиросов К.А. Управление технологической наследственностью при изготовлении нежестких валов. –Ташкент.: «Fan va texnologiya», 2010 г. -200 с.
2. Шаабидов Ш.А., Иргашев А. Мирзаев К.К. Повышение эксплуатационных свойств поверхностных слоев деталей машин. Монография. Ташкент. 2012. -180 с.
3. Halas W., Taranenko W., Swic A. Modelling the accuracy of axialsymetricc shaft manufacturing. PROCEEDINGS 31th CONFERENCE ON PRODUCTION ENGINEERING OF SERBIA AND MONTENEGRO 2006. 19-21 september 2006, Kragujevac, Serbia and Montenegro, Kragujevac, 2006. s. 305-310.
4. Драчев А.О., Расторгуев Д.А., Тараненко Г.В., Тараненко В.А. Прогрессивная технология термосиловой обработки нежестких деталей типа вал. Прогрессивные технологии и системы машиностроения: Международный сборник научных трудов. – Донецк: ДонНТУ, 2009. Выпуск 38. С. 208-218.