Automatic control of the shaft hot straightening process

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Abstract. The article discusses the installation equipped with ACS, which allows you to automatically diagnose and control the technological operation - axial straightening of low-rigid shafts. The value of axial loading is applied to the workpiece in the function of thermal elongation in such a way that the ratio of applied tensile stresses to the stress corresponding to the yield strength remains until the moment of phase transformation. The installation is equipped with a static and dynamic loading mechanism and two ACS diagnostic channels.

1. Introduction
In the works devoted to the influence of residual stresses on the operational accuracy of low-rigid parts the calculations of residual stresses are mainly given [1-4,8-18]. The paper discusses the technological method of axial hot straightening by stretching (OGPR) under the condition of phase transformation of the workpiece material. In work [1] it is shown that at deformation of metals in the conditions of development of phase transformation there is a sharp increase in plasticity. This effect is observed both at diffusion and martensite transformations. These facts indicate that the moment of phase transformation, regardless of its mechanism, favors the development of plastic flow processes.

2. Relevance and purpose of the study
The effect of superplasticity in phase transformation depends on the strength of the phases involved in the phase transition. Superplasticity is caused by internal stresses resulting from the difference in specific volumes of the transforming and newly formed phases. A methodology for using the effect of superplasticity to increase the operational accuracy of low-rigid shafts has been proposed on the basis of developments [2,5-9].

3. Main discussion points
The peculiarity of such an approach is that the static voltage is applied in the case of OGPR, the value of which decreases in the function of temperature elongation, while starting with the advance of the given temperature the ratio of applied tensile stresses to the voltage corresponding to the yielding capacity remained constant until the onset of phase transformations. In addition, in the workpiece additionally excite bending vibrations at its own frequency, recording the frequency deviation and reduction of amplitude, controlling the selection of the active component of the energy of the self-exciting generator of excitation of bending vibrations in the function of the energy minimum value, form the control signals corresponding to the beginning of phase transformations and the permissible value of 02 under the influence of temperature and force factors. Simultaneously fix new value of frequency and amplitude of bending vibrations and form criterion of estimation $K_f$ - reception of the set physical-mechanical properties of a material, in relation to natural frequencies of preparation in a mode of heating.
frequency of natural vibrations in a mode of release $f_n$, $K_f = f_n / f_0 \leq 1$ and the less the relation of frequencies, the higher physical-mechanical properties of preparation.

4. Main body

The essence of the methodology is explained by the scheme in Fig. 1, which shows the general view of the installation and functional control scheme with the design features of CGTR installation for non-rigid shafts [5]. The control of the process of the non-rigid CCPD rolls is carried out as follows. In electric furnace 1, billet 2 is installed relative to slipway 3, and one end of the billet is fastened to the plate 4. Control of the process of non-rigid shafts is carried out as follows. In the electric furnace 1 set billet 2 relative to the slipway 3, with one end of the blank attached to the plate 4 of the mechanism of quasi-static loading.

![Figure 1. OPGC installation for metals with phase transformations.](image)

Plate 4 has the ability to move upwards under the influence of load springs 5 on the guideways 6. Axial tensile force is determined from the condition $P_p = K \cdot X_1$, $P_p = K \cdot X_1$.

Hard fixation of the workpiece relative to the plate 4 is carried out by the lock 7, when cooled down the workpiece is moved down (compressed), and its movement is regulated by electromechanical limiter of the workpiece 8, controlled by the first relay control regulator 9. The electromagnetic vibrator 10 is mounted on the slipway 3, which provides the fluctuations of the workpiece 2 at the first resonant frequency in the mode of release. Workpiece extension 2 in the process of heating is controlled by the sensor of 11 linear movements, and its signal, converted into an electric one, goes to the ACS diagnostics channel.

In the initial state after fixing the workpiece 2 in the lower part of the slipform pavilion, the springs 5 are compressed by electromechanical drive 12 from the second relay of the regulator 13, providing free passage of workpiece 2 through the central hole of the plate 4.

Then, blank 2 is fixed relative to the plate 4 with the stopper 7, i.e. the upper free end of blank 2 is closed on the plate 4 end. Then release pre-compressed springs 5 by controlling the tensioning mechanism 12 from the electric actuator 13, providing loading of the workpiece with 2 axial force $P_p = K \cdot X_1$, where, $X_1$ - the compression of the springs under the action of the working load, in this case the maximum, which is selected on the basis of geometric parameters and physical and mechanical properties of the workpiece. Workpiece 2 is loaded with axial tensile force in starting position $P_p$ by means of springs 5 (the number of springs is selected according to the required axial force) through the
plate 4. Then switch on electric furnace 1 and control the increase of furnace heating temperature with the help of the primary converter of temperature registration 14 connected to the input of potentiometric amplifier 15. The amplifier output signal 15, proportional to the furnace temperature, is recorded using the multi-input recorder 16. At the same time, the value of the temperature elongation of workpiece 2 is recorded with the help of the sensor of 11 linear movements, the primary converter of the temperature elongation registration, the output of which is also connected to the multi-input recorder 16.

Simultaneously with the heating of the workpiece 2 it is stimulated by bending vibrations in the mode of tempering at its own resonant frequency, taking into account the reduced mass of the mechanism of static loading, with the help of electromagnetic vibrator 10, installed on the top of the slipway 3. Electromagnetic vibrator is connected to the output of the self-excited generator 17. And to evaluate the selection of the active component of energy from the generator, the electromagnetic vibrator 10 is included in one of the shoulders of the impedance bridge.

Under the influence of temperature-force factors, the linear elongation of the shaft 2 increases, Fig. 1, resulting in a change in the stroke of X1 springs 5. The value of axial force applied to the shaft 2 is chosen in such a way that, starting from a certain, ahead of a given temperature, the ratio of applied tensile stress $\sigma_p$ to the yield strength of $\sigma_{02}$ remained constant until the onset of phase transformations (appearance of superplasticity). Such a mode of stabilization of this ratio is provided automatically by reducing the forces of the axial static load under the influence of the changing value of the spring stroke and voltage change from the temperature of Fig. 2 (curve 5). While ensuring the continuity of the connection $\sigma_p / \sigma_{02}$, where $\sigma_p$ — working normal

![Figure 2. Temperature dependence of plasticity](image)

Where curve 1 - expected plasticity, curve 2 - state of superplasticity, curve 3 - yield strength dependence on temperature, curve 4 - normal operating stresses dependence on temperature, curve 5 - linear elongation dependence on workpiece heating temperature.

Spring stress, $\sigma_{02}$ — yield strength, provided that the irreversible residual strain is 0.2%, despite the increase in the length of the workpiece, the natural frequency of the subsystem "shaft-support" remains constant due to the stabilization of the rigidity of the specified subsystem. In case of failure to maintain the ratio, the stiffness of the subsystem "shaft-support" changes, and therefore, changes (decreases) its own resonance frequency. Changes in frequency in such a case carry the information about the violation of the specified attitude $\sigma_p / \sigma_{02}$ and, consequently, the failure to provide the specified temperature and force factors of influence. Recording of changes in frequency, amplitude and active component of the power of dynamic influence is carried out by means of two interconnected channels.

The initial value of the natural resonance frequency $f_n$ of the support shaft corresponds to the heating mode and the frequency change $f_o$ corresponds to the holiday mode and is detected by the diagnostic channel. The formation of the control signal and the implementation of the criteria for evaluating the
desired properties of the material to be machined in relation to the natural frequencies of the workpiece $K = f_a / f_o$ is carried out by a second diagnostic channel as follows. The output voltage of the self-excited generator 17 with the frequency $f_o$ in heating mode is converted by the block (block of the vibration frequency converter into an analog signal) into analog voltage, which is fed to the second channel of the recorder 16. At the moment when phase transformations occur, the operator registers the value $f_o$ in tempering mode. The frequency $f_o$ accept the frequency corresponding to the stiffness of the "shaft-support" subsystem in elastically-stressed state and the temperature of the end of tempering. Knowing the frequencies $f_a$ and $f_o$, you can assess their attitude as a criterion $K = f_a / f_o$, the smaller the value of the ratio is, the higher the physical and mechanical properties of the workpiece.

Presence of two contours of formation of diagnostic signs and regulation by modes of OGPR, and also mechanical stabilization of the relation $\sigma_p / \sigma_{o2}$ with the automatic drive of the mechanism of fixing of preparation, allow to automate completely technological process and to receive a detail of the set quality. OGPR allows, along with obtaining the specified physical and mechanical properties, to obtain an equal-stressed state along the length of the workpiece and provide high operational accuracy.

5. Results of the research. Conclusion

Example of method implementation. Hardened samples from steel 30X13, mechanical properties of sorghum rolled products were subjected to tempering with geometric parameters, blank diameter 19 mm, length 1230 mm. Frequency of three own bending vibrations is 3.5 Hz, 14 Hz, 30.5 Hz. Vacation modes 700-750° and 600-620°. Static axial load developed by springs $\sigma = 4.2-21$ kgf/mm² depending on the number of springs. Amplitudes of pulsation of 2-12 kgf/mm² in a current of 20 minutes. Before the experiment, the workpiece was plastically deformed with a maximum radius of curvature of 5.56 mm. After processing by the offered method the billet was processed by electrochemical method, blown out on an external surface of a layer on depth 1 mm. Maximal workpiece warps were 0.05 g 0.065 microns. Operational accuracy increases in hundreds of times and is maintained during the whole period of operation.

References

[1] Kaibyshev O A 1975 Plasticity and superplasticity of metals (Moscow: Metallurgy) 280 p
[2] Drachev O I 2005 Technology of the low-rigid axisymmetric parts manufacturing (St. Petersburg: Polytechnics) 289 p
[3] Kolmogorov G L and Kurapova N A 1996 Limit modes of the axisymmetric deformation of metals Vestnik PGTU Technological equipment 2 16–24
[4] Pozdeev A A, Nyashin Y I and Trusov P V 1982 Residual stresses: Theory and appendices (Moscow: Science) 112 p
[5] Drachev O I and Palagniuk G G 1990 Method of automatic diagnostics and control of the process of thermomechanical processing of low-rigid parts and the device for its implementation A.S. 1561385 CF., MKI 5 IN23 Q15/00 (USSR) no. 4448143/31-08; declared. 11.05.88; op. 29.10.90, Bull. no. 28 10s.
[6] Drachev O I and Rastorguev D A 2012 Device for the thermal force processing of the low-rigid parts Patent 2462518 Russian Federation MPK7C21D8/06 Applicant and patent holder, Togliatti State University, №20010130208/02. Applied. 09.09.2010, published on 09.03.2012, Bull. no. 5 p 5
[7] Sokolov I A and Uralsky V I 1981 Residual stresses and quality of metal products (Moscow: Metallurgy) 96 p
[8] Tropotov A V 1981 Calculation of the residual stresses after the elastic-plastic deformation by the variation method Collection "Metal pressure processing" 8 (Sverdlovsk: UP1) pp 139–43
[9] Gruening A, Lebsanft M and Scholtes B 2011 Residual Stress State in Tools Used for Thermomechanical Metal Forming Processes. Engineering Applications of Residual Stress Part of the ser. Conf. Proceedings of the Society for Experimental Mechanics Ser. vol 8 pp 39–45 25 May
[10] Dong Ju, Epp J, Rocha A da S, Nunes R M and Zoch H W 2015 Investigation of the Influence
Factors on Distortion in Induction-Hardened Steel Shafts Manufactured from Gold-Drawn Rod *Metallurgical and Materials Transactions A* 1–12 25 Nov

[11] Nyashin LI and Kiryukhin V Y 2002 Biological stress in living tissues. The modeling and control problems *Russian J. of Biomechanics* 6(3) 13–31

[12] Nyashin Yu, Lokhov V and Ziegler F 2005 Stress-free displacement control of structures *Acta Mechanica* 175 45–56

[13] Nyashin Yu, Lokhov V and Ziegler F 2005 Decomposition method in linear elastic problems with eigenstrain *Zeitschrift fur Angewandte Mathematik und Mechanik* 85(8) 557–70

[14] Lokhov V, Nyashin Yu and Ziegler F 2009 Statement and solution of optimal problems for independent stress and deformation control by eigenstrain *Zeitschrift fur Angewandte Mathematik und Mechanik* 89(4) 320–32

[15] Sedov L I 1970 *Mechanics of continuous media* (Moscow: Nauka) 568 p

[16] Novak A, Berry B M 1975 *Relaxation phenomena in crystals* (Moscow: Atomizdat) 462 p

[17] Vishnyakov Y D and Piskarev V D 1989 *Residual voltage control in metals and alloys* (Moscow: Metallurgy) 250 p

[18] Nyanshin Yu I and Vishnyakov Yu I 1981 About management of process of processing of materials for the purpose of decrease of residual pressure *Applied mathematics and mechanics* 2