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STUDY OF THE TECHNOLOGICAL PARAMETERS OF THERMAL INFLUENCE FOR THE MATING PARTS WITH CTMA

Findings. *In to the article are given the results of theoretical studies, on the basis which are obtained new scientific approaches to the development of methodology and calculated dependences for determining the technological parameters of mating parts on the operation of their uneven heating and low-temperature cooling.*

Originality.*After accepting for the basis the methods of the theory of elasticity and thermal conductivity, the author scientifically substantiated the fundamental solutions, which will make it possible to obtain analytical dependences for determining the changes in the fit diameters of mating parts with CTMA.*

Practical value. *On their basis will be occurred the possibility to develop design models for determining the temperature parameters, changed in the time and ensuring the guarantee of fulfilling of technological process of assembling connections with the interference with the presence of temporary assembly-line clearance.*

Keywords: *the thermal methods of assembling connections with the interference, the technological parameters of the thermal influence*

For the selection of the rational energy-saving technological process, which ensures assembling connections with the interference of the increased strength, it is necessary to establish with the design of technology many input construction-engineering factors [1-3], in particular, the value of a change in the fit diameter of the components and heating temperatures and cooling for guaranteeing this change.

Object and the methods of the studies. By the subject of a study are selected the technological parameters uneven heating and the low-temperature cooling of the mating parts during assembling of connections with the interference with the use of thermal methods. With the solution of the problems, set in this work, the contemporary methods of the theoretical studies were used, which be based on the theory of thermoelasticity.

Formulation of the problem. Guarantee of a process of designing the connections with the interference “heavy interference fits” by design models and by the procedure of the optimum selection of the technological parameters the technology of assembling by different thermal methods, in particular, the value of a change in the fit diameter of components, and also temperatures of their uneven heating and cooling.

Results and their consideration. For determining these parameters will be obtained the calculated analytical models, which will make it possible to more accurately calculate them during the uneven heating and the low-temperature cooling. This task will be solved taking into account supply to the components of heat and cold over their external and internal surfaces, and also the temperature distribution in their tele- according to the linear or logarithmic laws depending on their thickness. For the thin-walled components the solution of problem will be carried out taking into account the linear law of distribution of temperature on their thickness, while for the thick-walled - logarithmic.

Dependence between a change in the temperature of body in the space and in the time establishes the differential equation of thermal conductivity, which takes the form, [4]

$$\frac{\mathrm{d}T}{\mathrm{d}r} = a\left(\frac{\mathrm{d}^2 T}{\mathrm{d}r^2} - \frac{1}{r}\cdot\frac{\mathrm{d}T}{\mathrm{d}r}\right), \qquad (1)$$

where T – the temperature, which is been the function of coordinates and time, ^{o}C; τ – the time, the hour; *a* – the coefficient of the thermal diffusivity m^2/ the hour; *r* – a radius of the cylinder.

An uneven change in the temperature of body causes in it the appearance of thermal stresses and deformations. After using generalized Hooke's law and after adding to the deformations, by the caused thermal stresses, temperature expansions (compression), are obtained the following formulas for the deformations [2]:

$$\varepsilon_z = \frac{1}{\mathrm{E}}\left(\sigma_z - \mu\sigma_r - \mu\sigma_\theta\right) + \alpha_T T = \text{const}, \quad \varepsilon_r = \frac{1}{\mathrm{E}}\left(\sigma_r - \mu\sigma_z - \mu\sigma_\theta\right) + \alpha_T T, \quad \varepsilon_\theta = \frac{1}{\mathrm{E}}\left(\sigma_\theta - \mu\sigma_x - \mu\sigma_r\right) + \alpha_T T \quad (2)$$

Expressing deformation through the displacements *U* $\varepsilon_r = \mathrm{d}U/\mathrm{d}r$, $\varepsilon_\theta = U/r$ and substituting the obtained values for σ_r and σ_θ in the equation of the equilibrium [4], we will obtain differential equation for the displacements:

$$\frac{\mathrm{d}^2 U}{\mathrm{d}r^2} + \frac{1}{r}\cdot\frac{\mathrm{d}U}{\mathrm{d}r} - \frac{U}{r^2} = \frac{1+\mu}{1-\mu}\alpha_T\frac{\mathrm{d}T}{\mathrm{d}r}. \qquad (3)$$

Solving equation (3) it is obtained dependence for determining in general form the displacements *U*:

$$U = \frac{1}{r}\cdot\frac{2+\mu}{1+\mu}\int_{r_1}^{r}\alpha_T Tr\,\mathrm{d}r + A\cdot r + \frac{B}{r}, \qquad (4)$$

where the expression for *A* and *B*

$$A = \frac{(1+\mu)(1-2\mu)}{1-\mu}\cdot\frac{1}{r_2^2 - r_1^2}\cdot\int_{r_1}^{r_2}\alpha_T Tr\,\mathrm{d}r - \mu\varepsilon_z, \quad B = \frac{1+\mu}{1-\mu}\cdot\frac{r_1^2}{r_2^2 - r_1^2}\cdot\int_{r_1}^{r_2}\alpha_T Tr\,\mathrm{d}r. \qquad (5)$$

After substituting (5) in (4) we will obtain dependence for determining the displacements in genera form into any time interval

$$\begin{gathered} U_i = \frac{1}{r}\cdot\frac{1+\mu}{1+\mu}\cdot\int_{r_1}^{r}\alpha_T T_i r\,\mathrm{d}r + \frac{(1+\mu)(1-2\mu)}{1-\mu}\cdot\frac{r}{r_2^2 - r_1^2}\cdot\int_{r_1}^{r_2}\alpha_T T_i r\,\mathrm{d}r - \\ -2\mu\frac{r}{r_2^2 - r_1^2}\cdot\int_{r_1}^{r_2}\alpha_T T_i r\,\mathrm{d}r + \frac{1}{r}\cdot\frac{1+\mu}{1-\mu}\cdot\frac{r_1^2}{r_2^2 - r_1^2}\cdot\int_{r_1}^{r_2}\alpha_T T_i r\,\mathrm{d}r, \end{gathered} \qquad (6)$$

where $T_{\mathrm{i}} = T(r)$ – the law of distribution of the temperature on the thickness of the wall of component at the assigned fixed moment of the time; r_2, r_1 and r – outside, inside and intermediate (flowing) radii of cylinder, correspondingly, mm; α_T – the temperature coefficient of linear expansion with the heating (compression - during the cooling), 1/K.

Taking into account that components are divided into the thick-walled, the thin-walled and the like of shells, in connection with this let us at first examine the case of uneven heating or cooling the cylinder of the type of thin-walled shell.

Let us examine the process of uneven heating (or cooling) in connection with to thick-walled cylinders taking into account the supply to them of heat or cold over the external surface or on the internal.

After considering that by heat- (or cold) brings to the external surface of thick-walled cylinder and temperature along its thickness is distributed according to the logarithmic law in the form

$$T = T_{\text{н}} = T_{\text{н}_{\ln}} \frac{\ln r - \ln r_1}{\ln r_2 - \ln r_1}, \tag{7}$$

where $T_{\text{н}_{\ln}}$ – temperature on the external surface of the cylinder.

Solving the integrals, entering in (4), taking into account (7) after conversions we will obtain expressions (8)

$$\int_{r_1}^{r} Tr \, \mathrm{d}r = \int_{r_1}^{r} \frac{\ln r - \ln r_1}{\ln r_2 - \ln r_1} r \, \mathrm{d}r = \frac{1}{(\ln r_2 - \ln r_1)} \cdot \frac{r^2 \left[2(\ln r - \ln r_1)\right] - 1 + r_1^2}{4}$$

$$\int_{r_1}^{r_2} Tr \, \mathrm{d}r = \int_{r_1}^{r_2} \frac{\ln r - \ln r_1}{\ln r_2 - \ln r_1} r \, \mathrm{d}r = \frac{1}{(\ln r_2 - \ln r_1)} \cdot \frac{r_2^2 \left[(\ln r_2 - \ln r_1)\right] - 1 - r_1^2}{2} \tag{8}$$

Let us substitute (8) into general solution (4) we will obtain formulas for determining the displacement on an inside radius r_1 and external r_2 of thick-walled cylinder with its heating outside

$$U_{r_1} = U_{r_1\,\text{цтн}} = \alpha_T\, T \cdot \frac{r_1}{r_2^2 - r_1^2} \cdot \left[r_2^2 - \frac{r_2^2 - r_1^2}{2(\ln r_2 - \ln r_1)} \right],$$

$$U_{r_2} = U_{r_2\,\text{цтн}} = \alpha_T\, T \cdot \frac{r_2}{r_2^2 - r_1^2} \cdot \left[r_2^2 - \frac{r_2^2 - r_1^2}{2(\ln r_2 - \ln r_1)} \right]. \tag{9}$$

After accepting the designation $r_2 / r_1 = 1 + m$ and after substituting it in (9), we will obtain

$$U_{r_1} = U_{r_1\,\text{цтн}} = \alpha_T\, T \cdot \frac{r_1}{m(2+m)} \cdot \left[(1+m)^2 - \frac{m(2+m)}{\ln(1+m)^2} \right],$$

$$U_{r_2} = U_{r_2\,\text{цтн}} = \alpha_T\, T \cdot \frac{r_2}{m(2+m)} \cdot \left[(1+m)^2 - \frac{m(2+m)}{\ln(1+m)^2} \right]. \tag{9}$$

The obtained by the author these results in the course of theoretical studies of the technological parameters of assembling the connections with the interference, attained with the thermal influence, are presented in the works.

Let us examine the case, when heat- brings to the internal surface of thick-walled cylinder and temperature along its thickness is distributed according to the logarithmic law

$$T = T_{\text{в}} = T_{\text{в}_{\ln}} \frac{\ln r_2 - \ln r}{\ln r_2 - \ln r_1}, \tag{10}$$

where $T_{\text{в}}$ – temperature on the inner cylinder face.

Solving the integrals, entering in (4) taking into account (10) after conversions we will obtain the solutions

$$\int_{r_1}^{r} Tr\,\mathrm{d}\,r = \int_{r_1}^{r} \frac{\ln r_2 - \ln r}{\ln r_2 - \ln r_1} r\,\mathrm{d}\,r = \frac{r_2^2 - r_1^2 - 2r_1^2(\ln r_2 - \ln r)}{\ln r_2 - \ln r_1} = \frac{r_2^2 - r_1^2}{\ln r_2 - \ln r_1} - 2r_1^2,$$

$$\int_{r_1}^{r_2} Tr\,\mathrm{d}\,r = \int_{r_1}^{r_2} \frac{\ln r_2 - \ln r}{\ln r_2 - \ln r_1} r\,\mathrm{d}\,r = 0 \cdot \tag{11}$$

After substituting expressions (11) in (4) we will obtain dependence for determining the displacement on the internal r1 and external r2 radii for the thick-walled cylinder with the heat supply or cold to its internal surface

$$U_{r_1} = U_{r_1\,\text{цтв}} = \alpha_T\, T \cdot \frac{r_1}{r_2^2 - r_1^2} \cdot \left[\frac{r_2^2 - r_1^2}{2(\ln r_2 - \ln r_1)} - r_1^2 \right],$$

$$U_{r_2} = U_{r_2\,\text{цтв}}\, \alpha_T\, T \cdot \frac{r_2}{r_2^2 - r_1^2} \cdot \left[\frac{r_2^2 - r_1^2}{2(\ln r_2 - \ln r_1)} - r_1^2 \right]. \tag{12}$$

After accepting the designation $r_2 / r_1 = 1 + m$ and after substituting it in (12), we will obtain

$$U_{r_1} = U_{r_1\,\text{цтв}} = \alpha_T\, T \cdot \frac{r_1}{m(2+m)} \cdot \left[\frac{m(2+m)}{\ln(1+m)^2} - 1 \right],$$

$$U_{r_2} = U_{r_2\,\text{цтв}} = \alpha_T\, T \cdot \frac{r_2}{m(2+m)} \cdot \left[\frac{m(2+m)}{\ln(1+m)^2} - 1 \right]. \tag{13}$$

On the basis obtained analytical results and data of precomputations are established that with an increase in the thickness of the wall of cylinder the extent of movements *U*, obtained on dependences (12, 13) with the logarithmic law of distribution of temperature on the thickness exceeds the data.

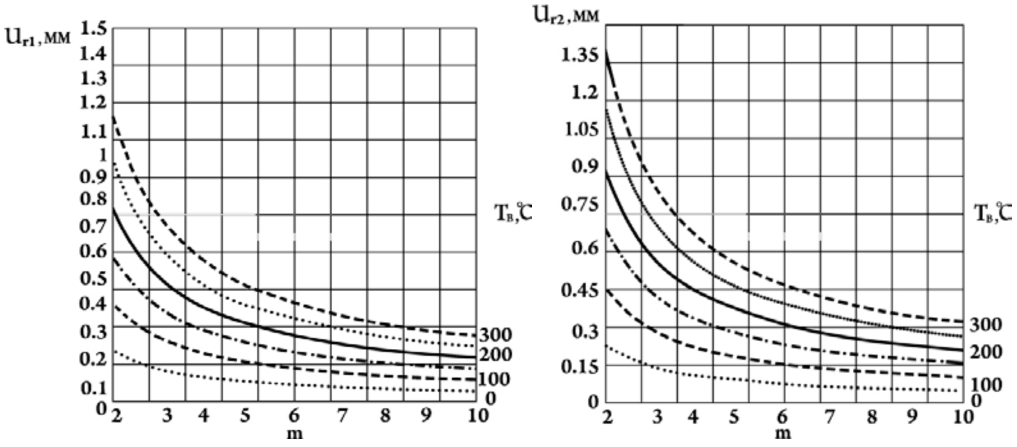
The obtained by the author results in the course of theoretical studies of the technological parameters of assembling the connections with the interference, attained with the thermal influence, are presented in the works are confirmed by the experimental-design method.

Important aspect with the development of the methodology of the realization of the technology of connections with the interference, as it was noted in division 1, is the selection of the rational direction of the heat supply or cold to the mating parts.

Thus, during assembling of connections with the interference of thick-walled components in the case of limiting the maximum temperature of heating external member by the possible structural irreversible phenomena and by the deformations of materials, it is necessary to bring heat- to the external surface of external member.

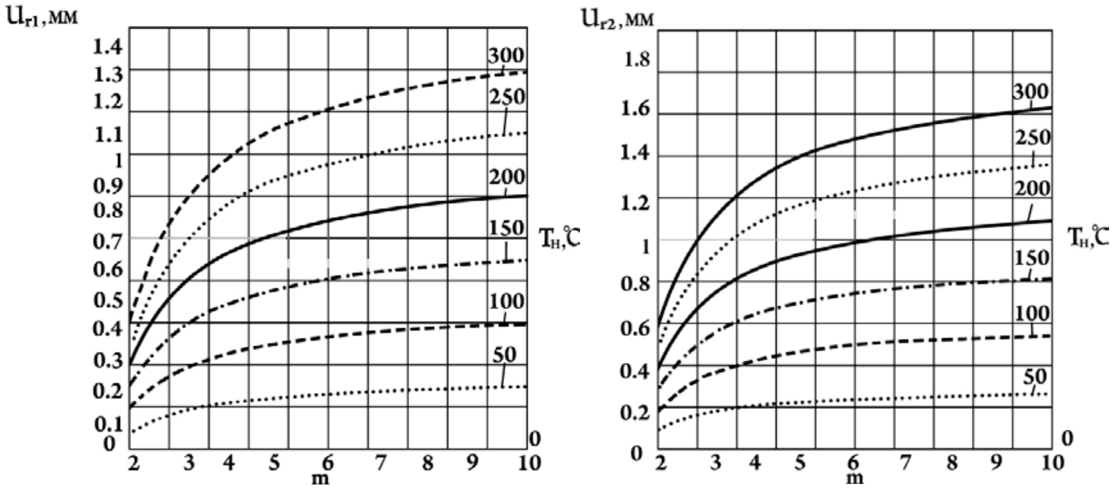
The fundamental nature of a change in the extents of movements with with the logarithmic law of distribution of the temperature in the dependence on the parameter m of the thickness of the wall of cylinder, temperature from the source of heat (cold) of $T_{\text{в}}$ on its internal surface or on the the external of $T_{\text{н}}$ on the basis dependences is examined based on the example of cylinder with a radius of the internal surface of 450 mm and external of 550 mm and is represented in the form graphs, correspondingly, in fig. 1 and 2.

It is established (fig. 1), that the extent of movements U, obtained on the dependence, with the logarithmic law of distribution of temperature and the heat supply (cold) with the temperature of $T_{\text{в}}$ to the inner cylinder face with an increase in the parameter m ($m = r_2/r_1 - 1$), i.e., the thickness of its wall, it decreases for the internal surface, so for the external surface. Extent of movements U (fig. 2), with the heat supply (cold) with the temperature of $T_{\text{н}}$ to the external surface of cylinder with an increase in the parameter m ($m = r_2/r_1 - 1$), i.e., the thickness of its wall, increase both for the internal surface and for the external surface.



a b

Fig. 1. Dependence of the extent of movements U from the relationship of radii of $r_2/r_1=1+m$ and temperature of $T_{\text{в}}$ on the inner cylinder face with the logarithmic law of its distribution on the thickness: a – for the internal surface; b – for the external surface.



а б

Fig. 2. Dependence of the extent of movements U from the relationship of radii of $r_2/r_1=1+m$ and temperature on the external surface of cylinder with the logarithmic law of its distribution on the thickness: a – for the internal surface; b – for the external surface.

In this case, after comparing data (fig. 1 and 2) it is possible to assert that the heat supply (cold) to the external surface of thick-walled cylinder will make possible to obtain 1,5 - 1,8 times of a change in the diameters of mating parts with CTMA higher than with the heat supply (cold) to the internal surface with the equal values of temperatures of $T_в$ and $T_н$.

On the basis executed theoretical studies and the obtained dependences for determining the displacements it is possible to create calculated analytical models for the calculated value of a change in the fit diameter during the uneven heating of external member and cooling included. These data make it possible to create the methodology of the determination of the assembly-line technological parameters for the qualitative realization of the technology CTMA of connections with the interference, in particular, the necessary temperature of mating parts taking into account of their geometric parameters, thermophysical properties of materials, possible directions of the heat supply and cold, laws of distribution of temperature.

It is established (fig. 1), that the extent of movements *U*, obtained on the dependences (18) and (19), with the linear law of distribution of temperature and the heat supply (cold) with the temperature of TV to the inner cylinder face with an increase in the parameter m ($m = r_2/r_1 - 1$), i.e., the thickness of its wall, it decreases for the internal surface, so for the external surface. Extent of movements *U* (fig. 2), with the linear law of distribution of temperature and the heat supply (cold) with the temperature of $T_н$ to the external surface of cylinder with an increase in the parameter m ($m = r_2/r_1 - 1$), increase both for the internal surface and for the external surface. Extent of movements *U* (fig. 2), with the linear law of distribution of temperature and the heat supply (cold) with the temperature of $T_н$ to the external surface of cylinder with an increase in the parameter m ($m = r_2/r_1 - 1$), increase both for the internal surface and for the external surface. In this case, after comparing data (fig 1 and 2) it is possible to assert that the heat supply (cold) to the external surface of cylinder will make possible to obtain 1, 5 - 1, 8 times of a change in the diameters of mating parts with CTMA higher than with the heat supply (cold) to the internal surface with the equal values of temperatures of $T_в$ and $T_н$.

Conclusions.

1. In to the article are given the results of theoretical studies, on the basis which are obtained new scientific approaches to the development of methodology and calculated dependences for determining the technological parameters of mating parts on the operation of their uneven heating and low-temperature cooling.
2. On the basis the analysis of obtained theoretical of given and analytical dependences it is established that the heat supply (cold) to the external surface of cylinder will make possible to obtain large changes in the diameters of mating parts with CTMA, than with the heat supply (cold) to the internal surface with the equal values of temperatures of $T_в$ and $T_н$.

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ДОСЛІДЖЕННЯ ТЕХНОЛОГІЧНИХ ПАРАМЕТРІВ ТЕРМІЧНОГО СКЛАДАННЯ З'ЄДНАНЬ ІЗ НАТЯГОМ СПОСОБОМ СКТС

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Результати. У статті наведені результати теоретичних досліджень, на підставі яких отримані нові наукові підходи до розробки методології й розрахункових залежностей для визначення технологічних параметрів деталей, що сполучаються, при їхньому нерівномірному нагріванні й низькотемпературному охолодженні.

Наукова новизна. На основі методів теорії пружності й теплопровідності, автором науково обґрунтовані принципові рішення, які дозволяють одержати аналітичні залежності для визначення змін посадкових діаметрів сполучуваних деталей при їх складанні способом КТСС.

Практична значимість. Ці залежності дозволяють розробляти розрахункові моделі для визначення температурних параметрів, змінюваних у часі й гарантуючому виконанні технологічного процесу складання з'єднань із натягом при наявності тимчасового складального зазору.

***Ключові слова**: термічні методи складання з'єднань із натягом, технологічні параметри термічного складання.*

ИССЛЕДОВАНИЕ ТЕХНОЛОГИЧЕСКИХ ПАРАМЕТРОВ ТЕРМИЧЕСКОЙ СБОРКИ СОЕДИНЕНИЙ С НАТЯГОМ СПОСОБОМ СКТС

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Результаты. В статье приведены результаты теоретических исследований, на основании которых получены новые научные подходы к разработке методологии и расчетных зависимостей для определения технологических параметров сопрягаемых деталей при их неравномерном нагревании и низкотемпературном охлаждении.

Научная новизна. На основе методов теории упругости и теплопроводности, автором научно обоснованы принципиальные решения, которые позволяют получить аналитические зависимости для определения изменений посадочных диаметров сопрягаемых деталях при СКТС.

Практическая значимость. Эти зависимости позволяют разрабатывать расчетные модели для определения температурных параметров, изменяемых во времени и гарантирующих выполнение технологического процесса сборки соединений с натягом при наличии временного сборочного зазора.

***Ключевые слова**: термические методы сборки соединений с натягом, технологические параметры термической сборки*