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NUMERICAL RESEARCH OF THE THERMALSTRESSED STATE OF PETROLEUM-HEATER OPTIONS AT INFLUENCE OF THE VEHICLE SYSTEMS PARAMETERS

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ABSTRACT

Bearing components of oil-heating installations in the form of stems, and also bearing components of the gas-generator plants, combustion engines, flight-type engines, and hydrogen engines are working in complex thermal and force field. In order to provide reliability of oil-heating installations in the form of stems it is necessary to ensure thermal durability of hardware characteristics, i.e. bearing components of the installations.

The paper presents the results of mathematical and numerical modeling of single-phase fluid flow in porous media with periodic microstructure. Object of study is the area in which the cylinders are arranged in a periodic manner. At the boundaries of the area for the flow parameters is set periodic boundary condition. Also in the paper presents comparison with Darcy's law and the calculation of the permeability coefficient for different values of the radius of the cylinders.

KEYWORDS: The Temperature, The Rod, The Thermal Energy, The Algorithm

INTRODUCTION

Consider a limited length pivot clamped at two ends, the cross-section of which is a circle and which changes along its length. The radius of the cross section linearly depends on the coordinates. Let`s denote the radius of the left end as r_0, the right end as r_L, and the length of pivotas L. Then the radius depends on a coordinate as follows

$$r = \frac{r_L - r_0}{L} \cdot x + r_0 \tag{1}$$

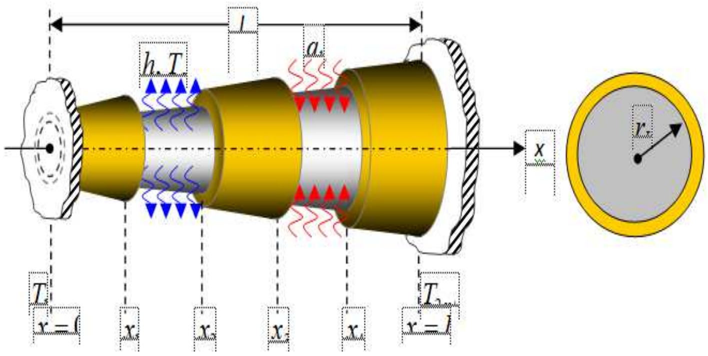


Figure 1: The Settlement Scheme of Tasks

SAMPLES AND ANALYTICAL METHODS

The temperature given on the left clamped end is $T(x=0)=T_1$, on the right is $T(x=L)=T_{2n+1}$. The side surfaces of sites on pivot $(0 \le x \le x_1)$, $(x_2 \le x \le x_3)$ and $(x_4 \le x \le x_L)$ were heat-insulated. A heat is exchanged with environment through the surface area of $(x_1 \le x \le x_2)$ sites. Thus coefficient of heat exchange is h, and temperature of environment is T_{co}. The thermal stream of permanent intensity q is brought on the area of side surfaces of sites $(x_3 \le x \le x_4)$. It is required numerically research the influence of the value $T_0 \in [(-150\ ^\circ C) \div (+150\ ^\circ C)]$.

On the field, the temperature distribution $(T=T(x))$, of elastic movement $(u=u(x))$, and also components of deformation $(\varepsilon_x=\varepsilon_x(x);\ \varepsilon_T=\varepsilon_T(x);\ \varepsilon=\varepsilon(x))$ and tension $(\sigma_x=\sigma_x(x);\ \sigma_T=\sigma_T(x);\ \sigma=\sigma(x))$. In order to develop a mathematical model of the field of temperature distribution along the length of a partly heat-insulated pivot which is limited length, it is sampled using quadratic elements with three nodes. Overall the number of elements will be n. Then the total number of nodes will be $(2n+1)$. When this sampling is conducted so that the borders of the elements will coincide with the borders of the heat-insulated part of the pivot. Then to each element is written functional expression that characterizes its full heat energy. In particular, for elements belonging to have a heat-insulated part of the pivot

$$I_i = \int_{V_i} \frac{K_{xx}}{2}\left(\frac{\partial T}{\partial x}\right)^2 dV,\ (i=1,\ 2,\ ...) \quad (2)$$

where V_i - volume of *i* element.

For elements located in the area of the pivot through the side surface of site where heat exchange takes place, the expression of the corresponding functional has the next form

$$I_j = \int_{V_j} \frac{K_{xx}}{2}\left(\frac{\partial T}{\partial x}\right)^2 dV + \int_{S_{jsss}} \frac{h}{2}(T-T_{co})^2 dS,\ (j=1,\ 2,\ ...) \quad (3)$$

where V_j - volume of *j*-elements, $S_{j\Pi Б\Pi}$ - area of side surface of *j*-element.

For elements located in the area of the pivot on the side surface of sites in which brought the thermal stream of permanent intensity q, the functional expression that characterizes their overall thermal energy will be

$$I_k = \int_{V_k} \frac{K_{xx}}{2}\left(\frac{\partial T}{\partial x}\right)^2 dV + \int_{SkSSS} qT(x)dS,\ (k=1,\ 2,\ ...) \quad (4)$$

The general expression of the full functionality of thermal energy for the considered partly heat- insulated pivot with variable cross-section based on the availability of local temperatures, heat flow and heat transfer

$$I = \sum_{t=1}^{n} I_t \tag{5}$$

Minimizing this functional on the key values of temperatures a mathematical model of the field of temperature distribution on length of the investigated pivot is built in the form of a resolution of the system of linear algebraic equations

$$\frac{\partial I}{\partial T_t} = 0, \ (t = 2, 3, ..., 2n) \tag{6}$$

Both T_1 and T_{2n+1} are given, so the number of equations in the system (6) will be equal $(2n+1)$.

Solving the system with different values T_1 and fixed values T_{2n+1}, h, T_{co}, and q is numerically investigate the influence on the character of field of temperature distribution along the length of the pivot under consideration.

A mathematical model of the field distribution of elastic movements, and also components of deformation and tension is build after the construction of the field of temperature distribution along the length of the pivot. To do this investigated pivot sampled $\left(N = \frac{n}{2}\right)$ quadratic elements with three nodes. Then to each element is written functional expression of potential energy of elastic deformation, which has form

$$\Pi_i = \int_{V_i} \frac{\sigma_x \varepsilon_x}{2} dV - \int_{V_i} \alpha E T(x) dV, \ (i = 1, 2, ..., N) \tag{7}$$

where V_i - volume of *i*-element, $u = u(x)$ - field distribution of elastic movement, $\varepsilon_x = \frac{\partial u}{\partial x}$ - field distribution of elastic component deformation, $\sigma_x = E\varepsilon_x = E \cdot \frac{\partial u}{\partial x}$ - field distribution of elastic component tension, E –modulus of material elasticity of the pivot, α - the coefficient of thermal expansion of the pivot material, $T = T(x)$ - filed temperature distribution, which is determined from the solution of (6).

For the considered pivot as a whole, the expression of potential energy of elastic deformation is as follows

$$\Pi = \sum_{i=1}^{N} \Pi_i \tag{8}$$

Minimizing the last on the key values of elastic movement a mathematical model of the elastic movement distribution along the length of the investigated pivot is built in the form of a resolution of the system of linear algebraic equations

$$\frac{\partial \Pi}{\partial u_i} = 0, \ (i = 1, 2, ..., (2N+1)) \tag{9}$$

Solving this system the field of elastic movement is determined by assuming that it is distributed along the length of the pivot. According to that it builds the appropriate field distribution of deformation and tension components as follows

$$\varepsilon_x = \frac{\partial u}{\partial x};\ \varepsilon_T = -\alpha T(x);\ \varepsilon = \varepsilon_x + \varepsilon_T \quad (10)$$

$$\sigma_x = E\varepsilon_x;\ \sigma_T = E\varepsilon_T;\ \sigma = (\sigma_x + \sigma_T) \quad (11)$$

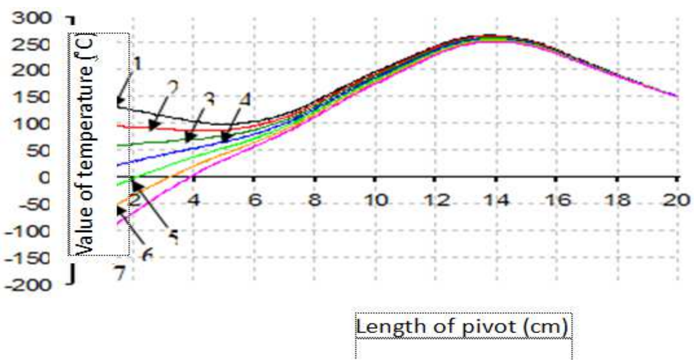
RESULTS AND DISCUSSIONS

To carry out numerical studies of the initial dates we use the following:

$L = 20\ (cm)$, $r_0 = 1\ (cm)$, $r_\ell = 2\ (cm)$, $n = 200$, $N = \frac{n}{2} = 100$, $q = -1000\ (W/cm^2)$, $K_{xx} = 100\ (W/(cm\cdot{}^\circ C))$, $h = 10\ (W/(cm^2\cdot{}^\circ C))$, $T_{co} = 40\ ({}^\circ C)$, $T_{401} = 150\ ({}^\circ C)$, and vary the value $T_1 \in [(-150\ {}^\circ C) \div (+150\ {}^\circ C)]$ with step $(-50\ {}^\circ C)$.

Consider the following example:

The value $T_1 = 150\ ({}^\circ C)$. In this case, the area bounded by the coordinate axes *OT*, *Ox* and *T*(*x*) will be equal $S_1 = 3507{,}259\ ({}^\circ C \times cm)$. Field of the temperature distribution along the length of the pivot under consideration is shown in Figure 2.

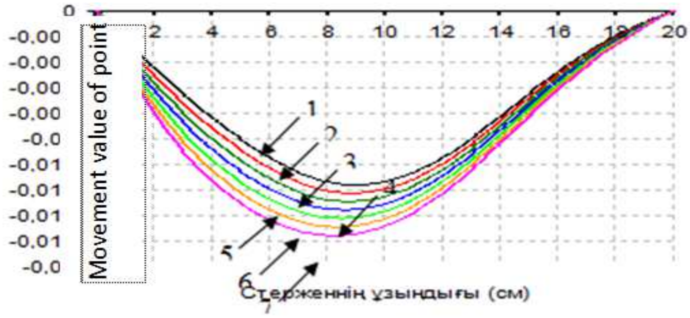


$1 - T_1 = 150\ {}^\circ C;\ 2 - T_1 = 100\ {}^\circ C;\ 3 - T_1 = 50\ {}^\circ C;\ 4 - T_1 = 0\ {}^\circ C;\ 5 - T_1 = -50\ {}^\circ C;$
$6 - T_1 = -100\ {}^\circ C;\ 7 - T_1 = -150\ {}^\circ C$

Figure 2: Field of Temperature Distribution in Different Values $T(x=0) = T_1$

From this figure, it is seen that the maximum temperature value which corresponds to the node coordinate is $x = 13{,}75\ (cm)$. In this node the value of temperature will be $T_{276} = 264{,}153\ ({}^\circ C)$.

The corresponding field distribution of elastic movement is shown in Figure 3.



Length of pivot (cm) $1 - T_1 = 150\ ^\circ C;\ 2 - T_1 = 100\ ^\circ C;\ 3 - T_1 = 50\ ^\circ C;\ 4 - T_1 = 0\ ^\circ C;$

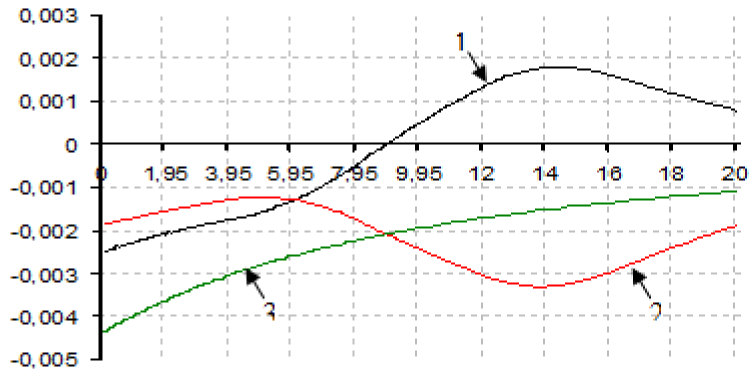
$5 - T_1 = -50\ ^\circ C;\ 6 - T_1 = -100\ ^\circ C;\ 7 - T_1 = -150\ ^\circ C$

Figure 3: The Field Distribution of the Movement at Different Values

$T(x = 0) = T_1$

It can be seen that the all cross section (except the clamped end) of the pivot move against the direction of the axis Ox. Thus in this direction moves the largest cross section whose coordinate is $x = 8{,}9\ (cm)$. The amount of movement of the cross-section is $u_{90} = -0{,}0135704\ (cm)$.

In this case, the field distribution of the elastic component of deformation along the length of the considered variable cross-section of the pivot has a compressive stretching in nature. This field is shown in Figure 4. It is interesting to note that the behavior ε_x of the section $0 \le x \le 8{,}85\ (cm)$ of the pivot will be compressed and then stretched. Thus the highest compressive value of ε_x corresponds to the section of coordinate which is $x = 0{,}15\ (cm)$ and a value is $\varepsilon_x = -0{,}0024920$. While the greatest tensile value of ε_x corresponds to the cross section of which coordinate is $x = 14{,}45\ (cm)$. The highest value of $\varepsilon_x = 0{,}0017948$.



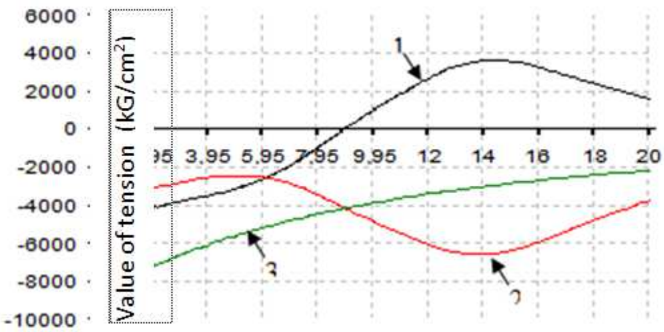
Length of pivot (cm) $1 - \varepsilon_x;\ 2 - \varepsilon_T;\ 3 - \varepsilon = \varepsilon_x + \varepsilon_T$

Figure 4: Field Distribution of Components Deformations in $T(x = 0) = T_1 = 150\ (^\circ C)$

The behavior temperature of components deformation ε_T throughout the length of the considered variable cross-section of the pivot will have a contractive nature. This can be seen from Figure 4. Thus the greatest value of compressive temperature component of deformation will be equal to $\varepsilon_T = -0{,}0033019$ and it corresponds to the cross-section of which coordinate is $x = 13{,}75\ (cm)$.

The behavior of the thermoelastic component of deformation $\varepsilon = \varepsilon_x + \varepsilon_T$ along the entire length of the considered pivot will be compressive. The field distribution of this component of deformation ε is as shown in Figure 4. The greatest value of compressive deformation of a thermoelastic component *accounts* for pinching the left end of the pivot, where the radius is twice less than the right end. On the left end of the radius pivot is $r = 1\ (cm)$. Figure 4 also shows that the field distribution of the thermoelastic component of deformation described by a smooth curve. The value of ε at the right end of the pivot is less than 3.94 times, than the left end. This phenomenon is due to the fact that the radius of the right end of the pivot is twice more than the left.

Field distribution of elastic component voltage σ_x is shown in Figure 5. They show that σ_x has in area $0 \le x \le 8{,}85\ (cm)$ compressed, and then stretching nature. Thus the highest compressive elastic voltage *falls* to the left pinching the end where $T_1 = T(x=0) = 150\ (^\circ C)$, and the radius is $r = 1\ (cm)$. At this end, the value of $\sigma_x = -4983{,}973\ (kG/cm^2)$. The greatest tensile value of σ_x corresponds to the cross-section of the pivot which coordinate is $x = 14{,}45\ (cm)$. In this section the value of the tensile elastic components of voltage $\sigma_x = 3589{,}658\ (kG/cm^2)$. This is 1,388 times less than the absolute value of the highest compressive voltage. The behavior of the temperature component of the voltage shown in Figure 5. It should be noted that the entire length of the pivot nature of the temperature component of voltage will be compressed. Thus in the section $0 \le x \le 4{,}95\ (cm)$ of the pivot has a step-down in nature. In the section $5{,}05 \le x \le 13{,}75\ (cm)$ of the pivot value of σ_T increases, and then decreases again. Thus the greatest value is $\sigma_x = -6603{,}841\ (kG/cm^2)$ and it corresponds to the cross section of the pivot, which coordinate is $x = 13{,}75\ (cm)$. This process is due to the fact that in this section of the pivot temperature is the highest $T_{276} = 264{,}153\ (^\circ C)$.



Length of pivot (cm) $1 - \sigma_x$; $2 - \sigma_T$; $3 - \sigma = \sigma_x + \sigma_T$

Figure 5: Field Distribution of Components Voltage in $T(x=0) = T_1 = 150\ (^\circ C)$

Figure 5 shows that the behavior of the thermoelastic component of the voltage $\sigma = \sigma_x + \sigma_T$ will be decreased monotonically along the length of the pivot.

The maximum value will be on the left end of pinching and minimal on the right. This is due with different cross-sectional areas of the pivot ends. For example, on the left clamped end of pivot value of thermoelastic tensions components is $\sigma(x = 0{,}05) = -8681{,}247\ (\kappa\Gamma / c\mathit{м}^2)$, on the right end it is equal to $\sigma(x = 19{,}95) = -2203{,}097\ (\kappa\Gamma / c\mathit{м}^2)$. This shows that $\frac{\sigma(x = 0{,}05)}{\sigma(x = 19{,}95)} = 3{,}94$ times.

So, at thermal expansion considering pivot with two clamped ends of variable cross section and limited length occurs compressive force R, which is the opposite axial direction by the two clamped ends. Its value is based on Hooke's law as follows:

$$R = \sigma_n \cdot F_n$$

where σ_n - thermoelastic tension in*n*`s element, $F_n$ - area of middle cross section *n*`s element

$$F_n = \pi \cdot r^2 (x = 0{,}05) = \pi \cdot 1{,}0025^2 = 3{,}15732\ (cm^2)$$

In this key value of compressive force is equal $R_1 = \sigma_n (x = 0{,}05) \cdot F_n = -27409{,}4769\ (kg)$. Definitely, this is concerning more force. It should be noted that at large compressive forces there can happen buckling of pivot.

CONCLUSIONS

It has been numerically researched parameters of devices systems, that is, the temperature distribution of the field along the length of the heat-insulated pivot with a variable cross-section, while the presence of heat stream on the left end and heat transfer on the right.

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