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SIMPLIFIED CALCULATION OF LINES FOR HYDRAULIC DRIVE CONSIDERING THE CHANGE TEMPERATURE OF FLUID

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Abstract. The features of stabilization of fluid velocity in pipings are observed in the article. We propose a practical method of the calculation. Proposed method of modeling for calculation of the transient time with the receipt of the fluid flow in a large temperature difference between the fluid and the environment temperature.

Keywords: the piping, hydraulic calculation, a temperature, a viscosity, flow velocity

INTRODUCTION

Hydraulic drives, which work in a broad temperature range should have heat insulation to avoid any additional energy losses. It is associated with the temperature of the working fluid.

In operation such situations arise when the hydraulic units and part of the piping is not quite insulated from the thermal influence of the environment, which is especially important for mobile and aircraft drives. There are questions about operate time and operability of such units. Proposed the method for simplified calculating the hydraulic lines with the considering changes hydraulic temperature fluid.

The method for calculation is based on the general theoretical functions of the velocities of the working fluid from the fluid temperature.

BASIC MATERIALS

Important step for preliminary hydraulic calculation units is to decision the values of the temperature of the working fluid at the time of start of system. For subsequent investigations of multi-mode drives, their design and operating parameters were studied. The piping is taken as an object of investigation; it corresponds to conduits of hydraulic drive. The temperature of piping is temperature of environment ($T_{env.}$,ºC). Temperature fluid input in piping is equal to a temperature of the working fluid in the hydraulic system ($T_{w.f.}$,ºC). Pressure drop along the piping is fixed for the let down working fluid.

Feature of this case is to calculate the change of kinematic viscosity along the piping in several times. Decisional of the temperature distribution in the time and on the piping length, as well as finding of the values of the fluid velocity in terms of viscosity change are an essential components of the investigation. This is a necessary condition for the simulation of the process that gives an approximate calculation of the hydraulic drive performance under these conditions. Used a method that takes into account the different values of the temperature of the working fluid in distributed into elementary parts piping length.

The working fluid velocity calculated for a given pressure drop in hydraulic calculation of hydraulic conduits hydraulic drive, in many studies. For this purpose, the known formulas for finding the pressure drop [1, 12, 15], both laminar and turbulent flow, are known:

$$p_{in} - p_{out} = \Delta p = \alpha \cdot \frac{l \cdot \rho}{2 \cdot d} \cdot U^2 ,$$

wherein α – the coefficient of friction, which is decision fluid flow. For circular cross parts is decisional by the formulas:

– for laminar flow:

$$\alpha_{lam} = \frac{64}{\mathrm{Re}} = \frac{64 \cdot \upsilon}{U \cdot d} ;$$

– for turbulent flow:

$$\alpha_{turb.} = 0{,}3164 \cdot \mathrm{Re}^{-0{,}25} = 0{,}3164 \cdot \left(\frac{U \cdot d}{\upsilon} \right)^{-0{,}25} ,$$

wherein the coefficient of kinematic viscosity υ, which is a part of formula, is a function of working fluid temperature working fluid $\upsilon = f(T)$ [4, 10, 12].

The next step is to solve the problem of finding the temperature at some moment of time and in a certain parts of the piping. For simplified variant of decisional the temperature change ΔT is based on calculation of heat flux through the wall surface of the piping per unit of time should be determined. Simplified one is defined as:

$$q = -\lambda_{w.f.} \left(\frac{\partial \theta}{\partial x} \right)_V ,$$

wherein $\lambda_{w.f.}$ – coefficient of transcalency, $\lambda_{w.f.} = f(T)$ [2, 3, 10, 11].

The authors were considered proposals to decision the temperature in certain parts of the piping with the different dependencies [10,11].

For the proposed study were used formulas for define the temperature in the center of a cylindrical tube [3, 10, 12] with a known radius r and length l, viz.:

$$T_i = T_{w.f.} + \Delta T ,$$

wherein $\Delta T = \dfrac{q \cdot t}{c_p \cdot r \cdot \rho}$ [10, 11, 6].

Ingersoll L.R. and his co-authors proposed to decision the desired temperature using the following relationship [10]:

$$\frac{T - T_{env}}{T_{w.f.} - T_{env}} = S(\frac{a \cdot t}{l^2}) \cdot C(\frac{a \cdot t}{r^2}) ,$$

wherein T − temperature which is determined, $T_{env.}$ − environment temperature (walls), $T_{w.f.}$ − temperature of the fluid, which defines at the inlet, S − instant source of capacity (ratio of the amount of heat to the product of specific heat (ref. data) by density of the substance (ref. data):

$$S = \frac{Q}{c \cdot \rho} ,$$

wherein $Q = \lambda \cdot \dfrac{T_{env.} - T_{w.f.}}{r} F \cdot t$ or $Q = \alpha \cdot (T_{env.} - T_{w.f.})F$;

a − thermal (heat) diffusivity ($a = \dfrac{\lambda}{c \cdot \rho}$);

λ − coefficient of transcalency (ref. data).

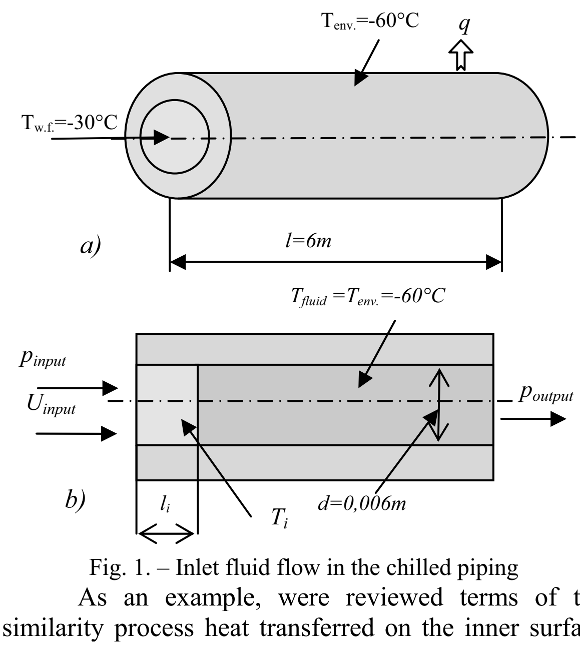

Fig. 1. – Inlet fluid flow in the chilled piping

As an example, were reviewed terms of the similarity process heat transferred on the inner surface of a smooth surface piping with a length l (m) and diameter d (m) (Fig.1. *a*), *b*)). The piping is a long time under the influence of external environment, fully cooled, i.e. the temperature fluid in the conduit has a value $T_{w.f.}$=$T_{evn.}$=-60ºC. At some parts of time the flow of the working fluid is supplied by the pressure drop Δp (Pa).

The temperature of pumping fluid $T_{w.f.}$= -30ºC. In piping is constant temperature from the environment, $T_{env.}$ = -60ºC. Hydraulic oil AMG-10 is taken as a working fluid, is used in a broad temperature range (to -60°C from +55°C) [4].

At the given stage for the simplification of the calculation the density of the working fluid ρ confirmed, as $\rho = const$.

The calculation of the fluid velocity as a function of the viscosity of the working fluid in all parts of the piping based on:

$$U_i \Rightarrow \Delta p = \alpha_{lam1} \frac{l_1}{d} \cdot \frac{\rho \cdot U^2{}_i}{2} + + (l - l_1) \cdot \frac{\alpha_{lam0}}{d} \cdot \frac{\rho \cdot U^2{}_i}{2} = U_i \cdot \frac{32}{d^2} \cdot \rho \sum_i^{i+1} (\nu_i \cdot l_i) ,$$

$$U_i = \frac{\Delta p \cdot d^2}{32 \cdot \rho(\sum_i^{i+1} (\nu_i \cdot l_i) + \nu_0 \cdot l_0)} . \quad (1)$$

The pressure drops over the length of l for the piping is defined by the formula:

$$\Delta p = \frac{1}{d} \cdot \frac{\rho \cdot U^2}{2} \int_0^l \upsilon(l) dl .$$

The temperature for the i-th part l_i for the considered case is defined by the formula:

$$T_i = \frac{\lambda^3 \cdot t^3 \cdot 2\pi \cdot (l_i + r) \cdot (T_{env} - T_{w.f.}) \cdot}{r^2 \cdot l_i{}^2 \cdot c \cdot \rho \cdot \sqrt{\dfrac{\lambda}{c \cdot \rho} \cdot \pi}} \cdot (T_{inv} - T_{w.f}) + T_{env} . \quad (2)$$

In further calculations, the coefficient of viscosity as a function of temperature is defined by the approximate experimental graphics (Fig.2).

Changing of the viscosity of the fluid greatly affects the performance of the hydraulic system. For example, for the oil AMG-10 at low temperatures the normal range of an operation corresponds the zone ***I***, permitted work done by – ***II***, critical work – ***III*** (Fig.2.) [4].

The basis of the calculation methodology consists of parts-supply of the fluid. The displacement process of chilled fluid to less cold fluid.

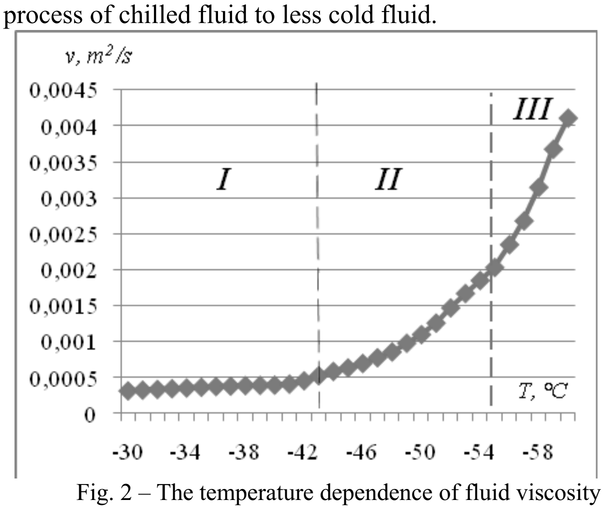

Fig. 2 – The temperature dependence of fluid viscosity of the AMG-10

Having defined the temperature of the working fluid for the function (2), has the function of the viscosity of the working fluid along the length of the piping with a batch of chilled fluid replacement. When you first traverse a part of fluid with temperature -30°C to the piping, it goes to the area l_i, and chilled to -34°C. The chilling part of the piping, i.e. $l - l_i$, at a temperature -60°C. As a result, obtain different values of viscosity corresponding to the temperature of fluid in different parts of the piping. As an example, the length 6 meters of piping is divided to 20 equal parts, which parts displacement fluid. Dependence ***1*** (Fig. 3) – is supply of fluid to the first five parts, the viscosity changes in range from $\upsilon_{-30} = 0{,}00032$ (*m²/s)* to $\upsilon_{-48} = 0{,}0025$ (*m²/s*), fluid on the remaining fifteen parts of the piping has a viscosity $\upsilon_{-60} = 0{,}004$ (*m²/s*). Dependence ***2*** – is supply of fluid to the first ten parts, the viscosity changes in the range from $\upsilon_{-30} = 0{,}00032$ (*m²/s)* to $\upsilon_{-55} = 0{,}0036$ (*m²/s*). Fluid on the remaining tenth parts of the piping has a viscosity $\upsilon_{-60} = 0{,}004$ (*m²/s*), dependence ***3*** – is third, respectively, on the supply of fifteen parts. Supply of fluid on the twenty parts of the piping, with a full displacement of fluid with a viscosity $\upsilon_{-60} = 0{,}004$ (*m²/s*) – dependence ***4*** (Fig. 3).

Dependences (Fig. 3) approximately describes the process of the viscosity stabilizing along the piping at a constant environment temperature of the piping and constant pressure drop.

Further, the hydraulic model is conventionally divided into several are parts. The piping with length *l=6 (m)*, for the phase displacement of fluid is divided into 20 parts with length $l_i = 0{,}3$ *(m)*.

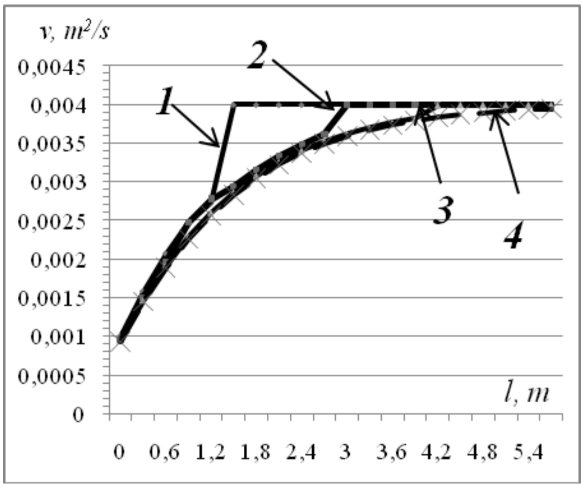

Fig. 3 – Change in viscosity of the fluid along the piping

Having defined the value of the temperature on sought-for part, define the value of viscosity, using the formula (1), identified the new velocity of the working fluid. The results of the calculation of temperature changes T_i°C and velocity in the *i-th* piping part with length *l* =6 (m) are summarized in Table 1. In the second step, we calculated the hydraulic model for piping with local resistance, as a sharp expansion (Fig. 4).

Table 1. The value of the temperature and velocity along a hydraulic model of the piping

Time for a full displacement of the chilled fluid t=84,65 s			Time of fluid displacement t=77,60 s, for the second run		Time of fluid displacement t=77,35 s, for the third run	
l, m	*T*, °C	U, м/с	*T*, °C	U, m/s	*T*, °C	U, m/s
0,3	-34,9612	0,02076	-34,9149	0,02562	-34,913	0,02584
0,6	-39,1949	0,02142	-39,1063	0,02566	-39,1028	0,02584
0,9	-42,7831	0,02199	-42,6573	0,02569	-42,6524	0,02584
1,2	-45,8055	0,02249	-45,6479	0,02571	-45,642	0,02584
1,5	-48,3374	0,02292	-48,1537	0,02573	-48,1469	0,02584
1,8	-50,4481	0,02329	-50,2439	0,02575	-50,2364	0,02584
2,1	-52,2001	0,02361	-51,9805	0,02577	-51,9725	0,02584
2,4	-53,6489	0,023901	-53,4187	0,02578	-53,4104	0,02584
2,7	-54,8431	0,024144	-54,6064	0,02579	-54,5978	0,02584
3	-55,8245	0,024354	-55,5848	0,02580	-55,5762	0,02584
3,3	-56,6289	0,024556	-56,3893	0,02581	-56,3807	0,02584
3,6	-57,2867	0,024734	-57,0497	0,02582	-57,0411	0,02584
3,9	-57,8235	0,024891	-57,591	0,02582	-57,5826	0,02584
-	-	-	-	-	-	-
6	-59,5316	0,025586	-59,4252	0,02585	-59,4187	0,02807

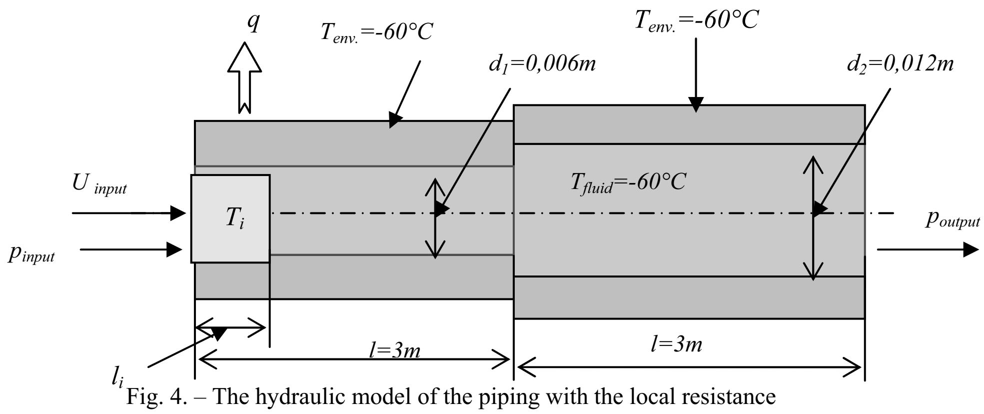

Fig. 4. – The hydraulic model of the piping with the local resistance

Similar to the first case, the velocity of working fluid was calculated for a given pressure drop, taking into account the coefficient of local resistance:

$$p_{in} - p_{out} = \Delta p = \Delta p_1 + \Delta p_{loc} + \Delta p_2; \quad (3)$$

wherein Δp_1 – pressure drop across the part l_1, and Δp_2 pressure drop across the part l_2, Δp_{loc} – pressure drop during the expansion. Velocity of working fluid along the piping accepts as the average for each part, i.e. $U = U_1$.

Value Δp_1:

$$\Delta p_1 = \alpha_{lam} \frac{l}{d} \cdot \frac{\rho \cdot U^2}{2} = \alpha_{lam1} \frac{l_1}{d_1} \cdot \frac{\rho \cdot U^2{}_1}{2} + \sum_0^i (l_1 - l_{1i}) \cdot \frac{\alpha_{lam1i}}{d_1} \cdot \frac{\rho \cdot U^2{}_1}{2},$$

wherein coefficients α_{lam} is for the first diameter are:

$$\alpha_{lam1} = \frac{64 \cdot \nu_1}{U_1 \cdot d_1}, \alpha_{lam1i} = \frac{64 \cdot \nu_{1i}}{U_1 \cdot d_1}.$$

Value Δp_2:

$$\Delta p_2 = \alpha_{lam} \frac{l}{d} \cdot \frac{\rho \cdot U^2}{2} = \alpha_{lam2} \frac{l_2}{d_2} \cdot \frac{\rho \cdot U^2{}_1}{2} + \sum_0^i (l_2 - l_{2i}) \cdot \frac{\alpha_{lam2i}}{d_2} \cdot \frac{\rho \cdot U^2{}_1}{2},$$

wherein coefficients α_{lam} is for the second diameter:

$$\alpha_{lam2} = \frac{64 \cdot \nu_2}{U_1 \cdot d_2}, \ \alpha_{lam2i} = \frac{64 \cdot \nu_{2i}}{U_1 \cdot d_2}.$$

Value Δp_{loc}:

$$\Delta p_{loc} = \xi_{loc1} \cdot \frac{\rho \cdot U^2{}_1}{2},$$

wherein ξ_{loc1} – coefficient of local resistance, which for the sharp expansion is defined by the formula:

$$\xi_{loc1} = (1 - n) = (1 - \frac{\omega_1}{\omega_2}),$$

wherein $\frac{\omega_1}{\omega_2}$ sectional area ratio of the transition [4].

Substituting the values in the formula (3), receive Δp:

$$\Delta p = (\frac{32 \cdot \nu_1 \cdot l_1 \cdot \rho \cdot U_1}{d_1^2} + \sum_0^i (l_1 - l_{1i}) \cdot \frac{32 \cdot \nu_{1i} \cdot \rho \cdot U_1}{d_1^2}) + \xi_{loc1} \cdot \frac{\rho \cdot U^2{}_1}{2} + (\frac{32 \cdot \nu_2}{d^1{}_2} \cdot \frac{l_2}{d^1{}_2} \cdot \frac{\rho \cdot U_1}{} +$$

$$+ \sum_0^i (l_2 - l_{2i}) \cdot \frac{32 \cdot \nu_{2i} \cdot \rho \cdot U_1}{d^2{}_2}) = 32 \cdot \rho \cdot U_1 \cdot \left((\frac{\nu_1 \cdot l_1 + \sum_0^i (l_1 - l_{1i}) \cdot \nu_{1i}}{d_1^2}) + (\frac{\nu_2 \cdot l_2 + \sum_0^i (l_2 - l_{2i}) \cdot \nu_{2i}}{d^1{}_2}) \right) + \xi_{loc1} \cdot \frac{\rho \cdot U^2{}_1}{2};$$

$$\Delta p = \xi_{loc1} \cdot \frac{\rho \cdot U^2{}_1}{2} + 32 \cdot \rho \cdot U_1 \cdot (\frac{\nu_1 \cdot l_1 + \sum_0^i (l_1 - l_{1i}) \cdot \nu_{1i}}{d_1^2}) + 32 \cdot \rho \cdot U_1 \cdot (\frac{\nu_2 \cdot l_2 + \sum_0^i (l_2 - l_{2i}) \cdot \nu_{2i}}{d^1{}_2}).$$

As a result, for the hydraulic calculation for model piping with coefficient of local resistance obtains the calculated flow velocity:

$$U_i \Rightarrow \frac{\xi_{loc1} \cdot \rho}{2} \cdot U^2{}_1 + 32 \cdot \rho \cdot \left(\left(\frac{\nu_1 \cdot l_1 + \sum_0^i (l_1 - l_{1i}) \cdot \nu_{1i}}{d_1^2}\right) + \left(\frac{\nu_2 \cdot l_2 + \sum_0^i (l_2 - l_{2i}) \cdot \nu_{2i}}{d^1{}_2}\right) \right) \cdot U_1 - \Delta p = 0$$

The velocity of the working fluid for the hydraulic model (Fig. 4.) is defined as:

$$U_{i(1,2)} = \frac{-32 \cdot \rho \cdot \left(\left(\frac{\nu_1 \cdot l_1 + \sum_0^i (l_1 - l_{1i}) \cdot \nu_{1i}}{d_1^2}\right) + \left(\frac{\nu_2 \cdot l_2 + \sum_0^i (l_2 - l_{2i}) \cdot \nu_{2i}}{d^1{}_2}\right) \right) \pm}{\xi_{loc\,1} \cdot \rho}$$

$$\frac{\pm \sqrt{\left(32 \cdot \rho \cdot \left(\left(\frac{\nu_1 \cdot l_1 + \sum_0^i (l_1 - l_{1i}) \cdot \nu_{1i}}{d_1^2}\right) + \left(\frac{\nu_2 \cdot l_2 + \sum_0^i (l_2 - l_{2i}) \cdot \nu_{2i}}{d^1{}_2}\right) \right)\right)^2 + 2 \cdot \xi_{loc\,1} \cdot \rho \cdot \Delta p}}{}$$

The resulting dependence of the fluid velocity stabilization is shown in Figure 5. Determination of the fluid velocity in the conduit was carried out for a complete displacement of the chilled fluid. Dependences of the stability process of the fluid velocity were the resulting for the two hydraulic models (Fig. 1, fig. 4). The first ousting process along the piping with length $l = 6$ (m) shown in range ***I***. Second and third ousting – respectively ***II*** and ***III***. Stabilization of the fluid velocity in piping of constant diameter describes the dependence ***1*** (Fig. 5). Dependence ***2*** describes the fluid velocity in piping with different diameters along its length. Numeral ***3*** indicates a time when the fluid flow approaches the place of the sudden expansion of the piping. Fluid velocity at this point is reduced due to the chilled of fluid. It increases the time of location of a certain part of fluid in piping (Fig.5).

The process of stabilization of the fluid velocity along the piping, depending on the temperature of the working fluid is decisional by the time of chilled fluid displacement (Fig. 5). On each of three of displacement the difference between of velocities at the beginning and end of the piping is:

(I) $\frac{U_{in}(l) - U_{in}(l_0)}{U_{in}(l)} = 2{,}163\,\%$, for piping ***1***, and for piping ***2*** it is 18,5%;

(II) $\frac{U_{in}(l) - U_{in}(l_0)}{U_{in}(l)} = 0{,}855\,\%$, for piping ***1***, and for piping ***2*** it is 3,187%;

(III) $\frac{U_{in}(l) - U_{in}(l_0)}{U_{in}(l)} = 0{,}028\,\%$, for piping ***1***, and for piping ***2*** it is 2,1228%.

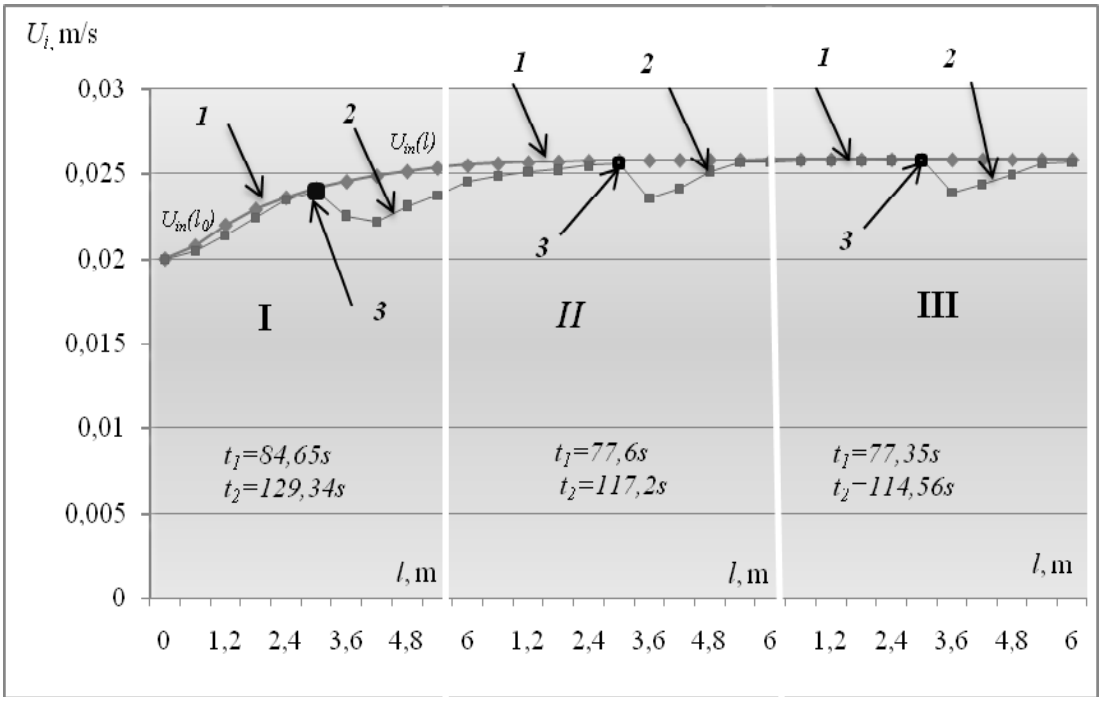

Fig.5. – Graph stabilization depending on the time velocity fluid passing along the piping for a few displacements

In the figure 5 are only three full-displacements, because the difference in time at full displacements in the following will be decrease:

for piping ***1***: $\dfrac{t(l_{II})-t(l_I)}{t(l_{II})}=8{,}3\,\%$;

$$\frac{t(l_{III})-t(l_{II})}{t(l_{III})}=0{,}32\,\%;$$

for piping ***2***: $\dfrac{t(l_{II})-t(l_I)}{t(l_{II})}=9{,}38\,\%$;

$$\frac{t(l_{III})-t(l_{II})}{t(l_{III})}=2{,}252\,\%.$$

The first full displacement chilled fluid from the piping for the two models of hydraulic are t_1 and t_2. It follows that the stabilization of the fluid velocity at low temperatures with the local resistance is significantly slower than without. Time to the fluid velocity at a stable velocity for the calculation of hydraulic models proposed piping significantly different. Velocity stabilization time in piping of constant has 25-30% more, than in the piping with different diameters.

CONCLUSIONS

This simplified the hydraulic method of calculation of piping lings for actuators during the start of hydraulic units in the low-temperature environment makes it possible to predict the time of the stabilization. The calculation of models the hydraulic piping with a large temperature difference between the working fluid at the beginning and at the end of the piping. It makes possible to describe the function of the viscosity and velocity of the working fluid while it starts working.

The proposed piping's hydraulic modeling makes it possible to take into account the importance of the effect of varying viscosity and temperature on the velocity of change of the working fluid. And the influence changes in the velocity of the fluid viscosity and temperature. Thus, the proposed method of calculation can decision the time of pre-start warming up fluid in the mobile and aviation hydraulic drives during operation at low temperatures.

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УПРОЩЕННЫЙ РАСЧЕТ ЛИНИЙ ГИДРАВЛИЧЕСКОГО ПРИВОДА С УЧЕТОМ ИЗМЕНЕНИЯ ТЕМПЕРАТУРЫ РАБОЧЕЙ ЖИДКОСТИ

Аннотация. В статье рассмотрены особенности стабилизации скорости потока рабочей жидкости в канале гидропривода и предложена практическая методика выполнения расчета. Предложена методика моделирования для расчета времени переходных процессов, с учетом поступления потока жидкости в условиях большой разницы между температурой жидкости и температурой окружающей среды.

Ключевые слова: трубопровод, гидравлический расчет, температура, вязкость, скорость потока