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RESEARCH ARTICLE

COMPUTATIONAL MODELS TO STUDY THE IMPACT OF SETTING OPTIONS OF ADJUSTING DEVICE ON DYNAMIC PROCESSES

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ABSTRACT

The developed methods and algorithms of calculating transition processes of the main oil pipelines are presented in the paper in an example of MOP, taking into account adjusting devices in the pumping station (PS), with a continuous regulation of operation (performance) of the PS.

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INTRODUCTION

The STUDIES have shown that the timing of the pressure recovery in the end, as well as any points of the pipeline, after disconnecting the intermediate pumping stations and other disturbances, is of practical importance for the automation issues of pipelines [1,2]. Calculation and examination of transients in the main pipeline with intermediate control elements, when the pump stops at one of the intermediate pumping stations or pumping, including an entire pump station is enabled (disabled), is a complex mathematical problem. Information about the dynamic processes at different disturbances, can prevent the accidents, and determine the performance of the remote control system for the information collection, and select the rational system of automatic control.

Relevance

Due to the changes in the performance of the pumping station (PS) when it is enabled or its separate units are disabled,the pressure in the pipe changes before and after oil pumping station (OPS). The change in the pressure after the disturbance source will affect the performance of the next OPS. In suchproblem statement, it is important to take into account the dynamic characteristics of the two adjoining sections of pipelineto OPS, moreover, at the start and end sections of the pipeline it is necessary to coordinate the amount of pressure change with the characteristics of related OPS [4]. Although this problem has not been studied enough, meanwhile, it includes a number of specific problems awaiting solutions. Mathematical solution of the problem requiressolving the equation ofthe adjuster jointly with the equation of motion control and stability of MOP.

The problem statement

In [3] the analysis of the operation mode of the main pipeline with multiple adjustable intermediate pumping stations is implemented on thebase of the proposed computational models in discrete adjustment of MOPperformance. Taking into account the impacts of adjusting devices on the transition processes the problem becomes much more complicated.

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In this context, this paper sets out the developed method and algorithm for calculating transients in MOP taking into account adjusting devices PS.

Solution method

In this work, double and discrete Laplace transform is used as the mathematical apparatus. The recurrence relations are applied in the transition from the image to the original functions [2]. Obviously, the development of calculation methods for the study of transients in MOPbecomes much more complicated during the smooth regulation of operation mode (performance) of the PS. In this case, the main pipeline should be viewed as a single system: - PS - pipeline with controller, which smoothly changes the performance of the PS [1].

Under such conditions, the problem is mathematically reduced to the solution of the equations of continuity and motion of unsteady so-called inlet and outlet sections of the main pipeline with the boundary conditions of the form as follows:

If $u = 0$ $\psi(0,t)=0$,
If $u=1$, $\xi=0$ $j(1,t)=J(0,t)$,$j(1,t)=k_4\psi(1,t)- k_5\varphi(0,t)+ k_6\eta(t)$, ……………………………………………(1)
If $\xi=1$ $J(1,t)=J$,

Where $\eta(t)$ is a variable, which characterizes the relative change in the parameter with the impact of the adjusting body on the performance of the PS, k_6- defines the extent of this impact on the performance.

To solve this problem we accept zero initial conditions, and boundary conditions (1) we transfer to the operator form:

If $u=0$ $\overline{\Psi}(0,s)=0$;
If $u=1$, $\xi=0$ $j(1,s)=\overline{J}(0,s)$; ………………………………..(2)
$j(1,s)=k_4\overline{\Psi}(1,s)-k_5\overline{\varphi}(0,s)+k_6\overline{\eta}(s)$;
If $\xi=1$ $\overline{J}(1,s)=\frac{1}{s}J$.

After the double Laplace transform the equations describing unsteady movement of fluid before and after the PS [2] in operator form are:

$$\overline{\Psi}(u,s) = -\frac{sk_1+k_2}{\gamma} sh\,\gamma u\,\overline{j}(0,s)\,, \qquad \text{…………………………………(3)}$$

$$\overline{j}(u,s) = ch\,\gamma u\,\overline{j}(0,s)\,, \qquad \text{…………………………………(4)}$$

$$\overline{\varphi}(\xi,s) = -\frac{sk_1+k_2}{\gamma} sh\,\gamma\xi\left[k_4\overline{\psi}(1,s) - k_5\overline{\varphi}(0,s) + k_6\overline{\eta}(s)\right] + \overline{\varphi}(0,s)ch\,\gamma s\,, \qquad \text{…………………………………(5)}$$

$$\overline{J}(\xi,s) = -\frac{sk_1+k_2}{\gamma} sh\gamma\overline{\varphi}(0,s) + ch\gamma\xi\times\left[k_4\overline{\psi}(1,s)-k_5\overline{\varphi}(0,s)+k_6\overline{\eta}(s)\right]\,. \qquad \text{…………………………………(6)}$$

Taking into account the boundary conditions (2), after some intermediate mathematical calculations for the functions included in (3÷6) we get:

$$\overline{\varphi}(0,s) = \frac{k_4}{a_5} ch\,\gamma\psi\,(1,s) - \frac{1}{a_5}\cdot\frac{J}{s}\,, \qquad \text{…………………………………(7)}$$

Where $a_5 = a_4 + k_6 b_{10}$, $a_4 = k_5 ch\gamma + \frac{\gamma}{sk_1+k_2} sh\gamma$, $b_{10} = \frac{a(1+Tu\cdot s)}{v\cdot Tu\cdot s}$, Tu- denotes the time of the isodrom of the isodromic adjuster; and a- as pecified speed of the servomotor; v – feed back velocity.

$$\overline{j}(0,s) = \frac{1}{ch\,\gamma}\left[k_4\overline{\psi}(1,s) - k_5\overline{\varphi}(0,s) + k_6\overline{\eta}(s)\right], \qquad \text{……………………………………..(8)}$$

$\overline{\psi}(1,s), \varphi(0,s)$ - accordingly, the images of the featuresψ(u,t) (ifu=1) andφ(ξ,t) (ifξ=0) or (8), taking into account (7)

$$\overline{j}(0,s) = \frac{\frac{k_4}{sk_1+k_2}\gamma ch\gamma}{ch\gamma(a_4+k_6 b_{10} ch\gamma)}\overline{\psi}(1,s) + \frac{J}{S}\cdot\frac{k_5+k_6 b_{10}}{ch\gamma(a_4+k_6 b_{10} ch\gamma)} \qquad \text{………………………………………(9)}$$

$\overline{\psi}(1,s)$ is determined through (3) by assuming u = 1 and taking into account (9), it is as follows:

$$\overline{\psi}(1,s) = -\frac{J}{s}\cdot\frac{(sk_1+k_2)(k_5+k_6b_{10})}{\gamma}\cdot\frac{sh\gamma}{ch\gamma(a_4+k_6b_{10}ch\gamma)+k_4sh^2\gamma} \quad .\qquad(10)$$

Using (9) and (10) in (3) for $\overline{\psi}(u,s)$ we obtain:

$$\overline{\psi}(u,s) = -\frac{J}{s}\cdot\frac{1}{\Delta_1}\cdot\frac{sk_1+k_2}{\gamma}\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)\cdot ch\gamma u \quad ,\qquad(11)$$

Where characteristic equation of the system is $\Delta_1 = k_4sh^2\gamma+\frac{\gamma}{sk_1+k_2}sh\gamma ch\gamma+\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)\cdot ch^2\gamma$.

Using (9) and (10) we obtain:

$$\bar{j}(0,s) = \frac{J}{s}(k_5+k_6b_{10})\frac{1}{ch\gamma(a_4+k_6b_{10}ch\gamma)+k_4sh^2\gamma},\qquad(12)$$

Or $\bar{j}(0,s) = \frac{J}{s}\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)\cdot\frac{1}{\Delta_1}$. (13)

Thus, taking into account (13) the equations (4÷6) will be as follows:

$$\bar{j}(u,s) = \frac{J}{s}\cdot\frac{1}{\Delta_1}\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)\cdot sh\gamma u \quad ,\qquad(14)$$

$$\overline{\psi}(\xi,s) = -\frac{J}{s}\cdot\frac{1}{\Delta_1}\cdot\frac{sk_1+k_2}{\gamma}\left[\left(k_4sh\gamma+\frac{\gamma}{sk_1+k_2}ch\gamma\right)ch\xi+\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)ch\gamma sh\gamma\xi\right] \quad ,\qquad(15)$$

$$\overline{J}(\xi,s) = \frac{1}{s}\cdot\frac{J}{\Delta_1}\cdot\left[\left(k_4sh\gamma+\frac{\gamma}{sk_1+k_2}ch\gamma\right)sh\gamma\xi++\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)ch\gamma u\cdot ch\gamma\xi\right]\qquad(16)$$

If t→∞, which corresponds to the obtained expressions γ=0, in the new mode of the pipeline we obtain the followings:

$$\psi_{ycm}(u) = -Jk_2u;\varphi_{ycm}(\xi) = -Jk_2\xi \quad ,\qquad(17)$$

$$j_{ycm} = J_{ycm} = J \; .$$

Thus, the obtained expression corresponds to the expression [2]..We can conclude that although the examined section of the pipeline is the endpoint and it is equipped with the system, which gradually changes the performance of the PS, and the size of the defined pressure value does not change.

In particular case, in the case of disturbance of inertial term in the initial equations [2]., we obtain the expression corresponding to [5].:

$$\overline{\psi}(u,s) = -\frac{J}{s}\cdot\frac{1}{\Delta_1'}\cdot\frac{k_2}{\gamma_1}\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)sh\gamma_1u \quad ,\qquad(18)$$

$$\bar{j}(u,s) = \frac{J}{s}\cdot\frac{1}{\Delta_1'}\cdot\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)sh\gamma_1u \quad ,\qquad(19)$$

$$\overline{\varphi}(\xi,s) = -\frac{J}{s}\cdot\frac{1}{\Delta_1'}\cdot\frac{k_2}{\gamma_1}\left[\left(k_4sh\gamma_1+\frac{\gamma_1}{k_2}ch\gamma_1\right)ch\gamma_1\xi++\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)ch\gamma_1\cdot sh\gamma_1\xi\right],\qquad(20)$$

$$\overline{J}(\xi,s) = \frac{1}{s}\cdot\frac{J}{\Delta_1'}\cdot\left[\left(k_4sh\gamma_1+\frac{\gamma_1}{k_2}ch\gamma_1\right)sh\gamma_1s+\left(k_5+k_6\frac{a}{v}\cdot\frac{1+sTu}{sTu}\right)\right],\qquad(21)$$

where $\gamma_1 = \sqrt{\frac{k_2 s}{k_3}}$, $\Delta_1' = k_4 sh^2\gamma_1 + \frac{\gamma_1}{k_2} sh\gamma_1 ch\gamma_1 + \left(k_5 + k_6 \frac{a}{v} \cdot \frac{1+sTu}{sTu}\right) ch^2\gamma_1$.

To obtain thecalculated expression of thetransient, according to the described method, the resulting equations are transformed into a discrete form, and using the convolution theorem, we obtain the calculated formulas for the required functions inthe domain of originals:

$$\psi[\delta,n] = -\frac{2J\sqrt{k_1k_3}}{k_4+c}\{\left(\sum_{m=0}^{n} k_5[m]\cdot 1[n-m] - \sum_{m=0}^{n} k_6[m]\cdot 1[n-m]\right)C +$$
$$+ D\left(\sum_{m=0}^{n} k_5'[m]\cdot 1[n-m] - \sum_{m=0}^{n} k_6'[m]\cdot 1[n-m]\right)\} + 2\frac{k_4-c}{k_4+c} \times \sum_{m=\lambda}^{n} k_1[m]\cdot\psi[n-m] - 2D\frac{1}{k_4+c}\times$$
$$\times \sum_{m=\lambda}^{n-1} k_1'[m]\cdot\psi[n-m] + \frac{k_4+c}{k_4-c}\times\sum_{m=2\lambda}^{n} k_2[m]\cdot\psi[n-m] - D\frac{1}{k_4-c}\sum_{m=\lambda}^{n-1} k_2'[m]\cdot\psi[n-m] - \frac{1}{(k_4-c)\sqrt{k_1k_3}}\times$$
$$\times\left(\sum_{m=0}^{n-1} k_3[m]\cdot\psi[n-m] - \sum_{m=0}^{n-1} k_4[m]\cdot\psi[n-m]\right) - \frac{D}{k_4-c} n\frac{T}{\lambda} - \sum_{m=0}^{n-1}\psi[m] \text{ ,} \quad \text{....................................(22)}$$

where $k©_1[m] = \sum_{m=0}^{n} k_1[m]; k©_2[m] = \sum_{m=0}^{n} k_2[m];$

$$k_{5,6}'[m] = \begin{cases} 0\,, \quad npu\ 0 \le m < \lambda(1\mp u) \\ \sum_{m=0}^{n}(e^{-\frac{\alpha mT}{2\lambda}m_1} I_0\left(\frac{\alpha T}{2\lambda}\sqrt{m^2 - [\lambda(1\mp u)]^2}\right) + \\ + \frac{\alpha T}{\lambda}\sum_{m_1=\lambda(1\mp u)}^{n}(e^{-\frac{\alpha T}{2\lambda}m_1} I_0\left(\frac{\alpha T}{2\lambda}\sqrt{m_1^2 - [\lambda(1\mp u)]^2}\right) \qquad ,m \ge \lambda(1\mp u) \end{cases}$$

The sign "-" refers to the original k_5' ,and «+» to k_6' .

In a particular case, if we neglect in the initial equations $\frac{\partial \bar{j}(u,t)}{\partial t}$, the design formula (21) is as follows:

$$\psi[\delta,n] = -\frac{2J\sqrt{k_2k_3}}{k_4+c}\{\left(\sum_{m=0}^{n} k_5''[m]\cdot 1[n-m] - \sum_{m=0}^{n} k_6''[m]\cdot 1[n-m]\right)C +$$
$$+ D\left(\sum_{m=0}^{n} k_5''[m]\cdot 1[n-m] - \sum_{m=0}^{n} k_6''[m]\cdot 1[n-m]\right)\} + 2\frac{k_4-c}{k_4+c}\times\sum_{m=0}^{n} k_1[m]\cdot\psi[n-m] - 2D\times$$
$$\times\frac{1}{k_4+c}\sum_{m=0}^{n-1} k_1''[m]\cdot\psi[n-m] + \frac{k_4+c}{k_4-c}\times\sum_{m=0}^{n} k_2'[m]\cdot\psi[n-m] - D\frac{1}{k_4+c}\sum_{m=0}^{n-1} k_2''[m]\cdot\psi[n-m] - \frac{1}{(k_4-c)\sqrt{k_2k_3}}\times$$
$$\times\left(\sum_{m=0}^{n-1} k_3'[m]\cdot\psi[n-m] - \sum_{m=0}^{n-1} k_4'[m]\cdot\psi[n-m]\right) - \frac{D}{k_4-c} n\frac{T}{\lambda} - \sum_{m=0}^{n-1}\psi[m], \quad \text{...................................(23)}$$

$$k©©_1[n] = erfc\sqrt{\frac{\lambda k}{nT}};$$

where

$$k©©_2[n] = erfc2\sqrt{\frac{\lambda k}{nT}}; k©_3[n] = \sqrt{\frac{\lambda}{\pi nT}};$$

$$k_4'[n]=\sqrt{\frac{\lambda}{\pi nT}}e^{-\frac{\alpha\lambda}{4nT}};k_5''[n]=2\sqrt{\frac{nT}{\pi\lambda}};$$

$$k_6''[n]=2\sqrt{\frac{nT}{\pi\lambda}}\exp\left(\frac{-4k\lambda}{nT}\right)-4\sqrt{k}erfc\left(2\sqrt{\frac{k\lambda}{nT}}\right);$$

$$k_5'''[m]=\sum_{m_1=0}^{m}k_5''[m_1];k_6'''[m]=\sum_{m_1=0}^{m}k_6''[m].$$

Original functions $j[\delta,n],\varphi[\delta,n],J[\delta,n]$are determined by the similar way.

All abovementioned proves that dealing with such problems with the use of the proposed method, there is no need for the decomposition of the coefficient of the expansion wave, and limiting with the first two terms, where, in fact, the systems with the distributed parameters are examined instead of the dynamics as a special case, the dynamics of the so-called balanced links. An analysis of the work shows that depending on the parameters' values, which take into account the friction and the repetition period of the lattice function, different errors occur [2]. Apparently, the greater the friction values and the repetition period of the lattice function, the more the value of the desired parameter of the specified mode and dynamics differs from the reality.

The Figures 1 and 2 show the theoretical pressure variation curves calculated with the expression (22) corresponding to different settings of the examined adjuster caused by increasing the load at the end point. The Figure 1: 1 - the curve is obtained if*a/s=0,18, Tu=25; 2*- the curve is obtained if*a/s=1, Tu=25; 3* - the curve a/s=1, *Tu=50; 4*- the curve *a/s=0,2, Tu=50.*

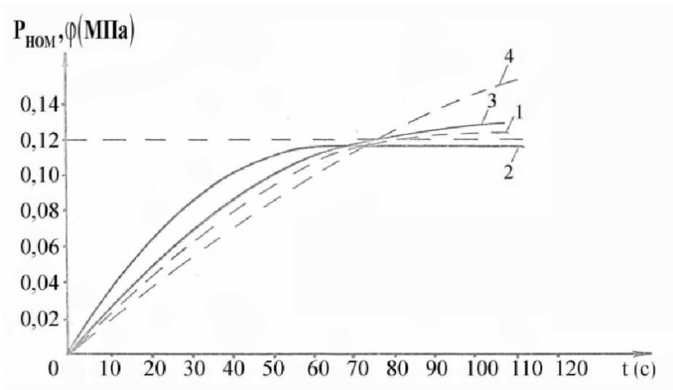

Fig. 1. The theoretical curves of transients in MOP at different settings of the adjuster

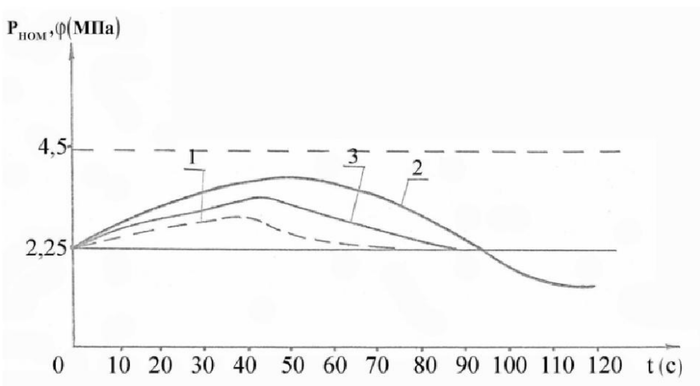

Fig. 2. The theoretical curves of transients in MOP at different settings of the pressure adjuster

The graph (Fig. 1, curves 1 and 3) shows that choosing the greater values of the constant time of the adjuster and the ratio of the feedback speed controller to the specified value of the speed of the servomotor (a/s) significantly delays the transition process and leads to overshoot.

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