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.

Keywords: *Main oil pipeline, Distributed options, Discrete method, Adjusting device, Initial and boundary conditions.*

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 pipelines automation issues of [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 such problem statement, it is important to take into account the dynamic characteristics of the two adjoining sections of pipe line to 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 requires solving the equation of the adjuster jointly with the equation of motion control and stability of MOP.

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

If
$$\xi = 1 J(1, t) = J$$
, (1)

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

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

$$\Psi_{(u,s)} = -\frac{sk_1 + k_2}{\gamma} sh\gamma u\bar{j}(0,s), (3)$$

$$J(u,s) = ch\gamma u\bar{j}(0,s), (4)$$

$$\varphi(\xi,s) = -\frac{sk_1 + k_2}{\gamma} sh \gamma [k_4 \bar{\psi}(1,s) - k_5 \bar{\phi}(0,s) + k_6 \bar{\eta}(s)] + \bar{\phi}(0,s) ch\gamma s , (5)$$

$$J(\xi,s) = -\frac{sk_1 + k_2}{\gamma} sh \bar{\phi}(0,s) + ch\gamma \xi \times [k_4 \bar{\psi}(1,s) - k_5 \bar{\phi}(0,s) + k_6 \bar{\eta}(s)]. (6)$$

Taking into account the boundary conditions (2), after some intermediate mathematical calculations for the functions included in $(3\div6)$ we get:

$$\bar{\varphi}(0,s) = \frac{k_4}{a_5} \operatorname{ch} \gamma \psi(1,s) - \frac{1}{a_5} \cdot \frac{J}{s}, \quad (7)$$

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

$$\bar{j}(0,s) = \frac{1}{\operatorname{ch} \gamma} [k_4 \bar{\psi}(1,s) - k_5 \bar{\phi}(0,s) + k_6 \bar{\eta}(s)], \quad (8)$$

 $\bar{\psi}(1,s), \varphi(0,s)$ - accordingly, the images of the features $\psi(u,t)$ (if u = 1) and $\varphi(\xi,t)$ (if $\xi = 0$) or (8), taking into account (7)

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

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

Where characteristic equation of the system is $\Delta_1 = k_4 \text{sh}^2 \ \gamma + \frac{\gamma}{sk_1 + k_2} \text{sh } \gamma \text{ch } \gamma + \left(k_5 + k_6 \frac{a}{v} \cdot \frac{1 + sTu}{sTu}\right) \cdot ch^2 \gamma - \text{Using (9) and (10) we}$ obtain:

$$\bar{j}(0,s) = \frac{J}{s}(k_5 + k_6 b_{10}) \frac{1}{ch\gamma(a_4 + k_6 b_{10} ch\gamma) + k_4 sh^2 \gamma}$$

(12)

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

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

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

$$\bar{\psi}(\xi,s) = -\frac{J}{s} \cdot \frac{1}{\Delta_1} \cdot \frac{sk_1 + k_2}{\gamma} \Big[\Big(k_4 \operatorname{sh} \gamma + \frac{\gamma}{sk_1 + k_2} \operatorname{ch} \gamma \Big) \operatorname{ch} \xi + \Big(k_5 + k_6 \frac{a}{v} \cdot \frac{1 + sTu}{sTu} \Big) \operatorname{ch} \gamma h\gamma \xi \Big],$$

(15)

 $\bar{J}(\xi, s) = \frac{1}{s} \cdot \frac{J}{\Delta_1} \cdot \left[\left(k_4 sh\gamma + \frac{\gamma}{sk_1 + k_2} ch \gamma \right) sh \gamma \xi + \left(k_5 + k_6 \frac{a}{v} \cdot \frac{1 + sTu}{sTu} \right) ch \gamma u \cdot ch \gamma \xi \right]$ (16)

If $t \rightarrow \infty$, which corresponds to the obtained expressions $\gamma = 0$, in the new mode of the pipeline we obtain the followings:

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

$$j_{ycm} = J_{ycm} = J.$$
(17)

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].:

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

$$\overline{r}(u,s) = \frac{J}{s} \cdot \frac{1}{\Delta_1'} \cdot \left(k_5 + k_6 \frac{u}{v} \cdot \frac{1+sTu}{sTu}\right) \operatorname{sh} \gamma_1 u, \tag{19}$$

$$\bar{\varphi}(\xi,s) = -\frac{J}{s} \cdot \frac{1}{\Delta_1'} \cdot \frac{k_2}{\gamma_1} \Big[\Big(k_4 sh\gamma_1 + \frac{\gamma_1}{k_2} ch \gamma_1 \Big) ch \gamma_1 \xi + \Big(k_5 + k_6 \frac{a}{v} \cdot \frac{1 + sTu}{sTu} \Big) ch\gamma_1 \cdot sh\gamma_1 \xi \Big]$$

$$\bar{J}(\xi,s) = \frac{1}{s} \cdot \frac{J}{\Delta_1'} \cdot \Big[\Big(k_4 sh\gamma_1 + \frac{\gamma_1}{k_2} ch \gamma_1 \Big) sh \gamma_1 s + \Big(k_5 + k_6 \frac{a}{v} \cdot \frac{1 + sTu}{sTu} \Big) \Big]$$
(20)

$$\gamma_1 = \sqrt{\frac{k_2 s}{k_3}}, \ \Delta_1' = k_4 \text{sh}^2 \ \gamma_1 + \frac{\gamma_1}{k_2} \text{sh} \ \gamma_1 \text{ch} \ \gamma_1 + \left(k_5 + k_6 \frac{a}{v} \cdot \frac{1 + sTu}{sTu}\right) \text{ch}^2 \ \gamma_1$$
(21)

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To obtain the calculated expression of the transient, 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 in the domain of originals:

$$\begin{split} \psi[\delta,n] &= -\frac{2J\sqrt{k_{1}k_{3}}}{k_{4}+c} \{(\sum_{m=0}^{n}k_{5}[m] \cdot 1[n-m] - \sum_{m=0}^{n}k_{6}[m] \cdot 1[n-m])C + \\ &+ D(\sum_{m=0}^{n}k'_{5}[m] \cdot 1[n-m] - \sum_{m=0}^{n}k'_{6}[m] \cdot 1[n-m]\} \\ &+ 2\frac{k_{4}-c}{k_{4}+c} \times \sum_{m=\lambda}^{n}k_{1}[m] \cdot \psi[n-m] - 2D\frac{1}{k_{4}+c} \times \sum_{n=\lambda}^{n-1}k'_{1}[m] \cdot \psi[n-m] \\ &+ \frac{k_{4}+c}{k_{4}-c} \times \sum_{m=2\lambda}^{n}k_{2}[m] \cdot \psi[n-m] - D\frac{1}{k_{4}-c} \sum_{m=\lambda}^{n-1}k'_{2}[m] \cdot \psi[n-m] \\ &- \frac{1}{(k_{4}-c)\sqrt{k_{1}k_{3}}} \times \times (\sum_{m=0}^{n-1}k_{3}[m] \cdot \psi[n-m] - \sum_{n=0}^{n-1}k_{4}[m] \cdot \psi[n-m]) \\ &- \frac{D}{k_{4}-c} n\frac{T}{\lambda} - \sum_{n=0}^{n-1}\psi[m] \\ &k'_{4}[n] = \sqrt{\frac{\lambda}{\pi nT}} e^{-\frac{\alpha\lambda}{4nT}}; k''_{5}[n] = 2\sqrt{\frac{nT}{\pi\lambda}}; \\ &k''_{6}[n] = 2\sqrt{\frac{nT}{\pi\lambda}} \exp\left(\frac{-4k\lambda}{nT}\right) - 4\sqrt{k} \operatorname{erfc}\left(2\sqrt{\frac{k\lambda}{nT}}\right) \\ &k''_{5}[m] = \sum_{m_{1}=0}^{m} k''_{5}[m_{1}]; k''_{6}[m] = \sum_{m_{1}=0}^{m} k''_{6}[m]. \end{split}$$

Original functions $j[\delta, n], \phi[\delta, n], J[\delta, n]$ 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.





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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