



Analysis of the Operation of the Systems with Distributed Parameters with the Adjusting System Objects

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Abstract An analysis of the trunk oil pipeline mode with multiple adjustable intermediate pumping stations is conducted on the example of the trunk oil pipeline basing on the developed computational models of transient processes in the systems with distributed parameters with the adjusting system objects.

Keywords: trunk pipeline, distributed parameter, discrete method, adjusting devices, initial and boundary conditions

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1. Introduction

The studies show that multi-level control systems with distributed parameters, an exact example of which is a complex oil pipeline systems, which are designed for and transportation of oil and oil products, have specific requirements for the development of decision-making tactics and strategy at all levels of the hierarchical management structure in order to provide reliability of technological problem solutions. Defining the duration of restoring the pressure in the end point, as well as at any point in the pipeline after turning off intermediate pumping stations and some other disturbances, is of practical importance in the issues of automation of pipeline control [1,2].

The study of transient processes also enables the development of the practical methods suitable for determination by relatively simple computations of hydrodynamic characteristics of pipelines and physical properties of pumped products. The calculation and study of transient processes in trunk pipelines with intermediate control elements, when the pumps are disabled at one of the intermediate pumping stations or the pumping, as well as entire pump station is enabled (disabled), is a complex mathematical task.

Knowledge of the characteristics of unsteady flow in dynamic processes is necessary to address the complex automation of trunk oil pipelines. Information about dynamic processes in various disturbing effects, enables to prevent the accidents, to determine the response of the remote control system for data collection, and to choose a rational system of automatic adjusting. Detailed information about the state of technological control object enables to

develop a complete set of files required to generate a database, as well as for the identification and management, both in vertical and horizontal hierarchical control system [2].

2. Relevance

The definition of the system state, its objects, identification of its parameters, adapting them to real operating conditions play the major role in the decision-making. The problem solution is actually confined to the restoration of the parameters on the system performance observed in the past. Obviously, decision-making on providing required system parameters or its separate objects, which are adapted to the previous state of the system, is unreliable. The theory system control with distributed parameters mainly includes the tasks associated with the identification of affecting functions in order to provide the required outlet parameters of the objects or the system as a whole [2,3].

Solution of such practical problems is of great theoretical and practical interest and importance in the theory and practice of the exploitation of the systems with distributed parameters.

Regarding to the intensive development and specific technological features, complex pipeline systems for the transportation of oil and oil products, which is of great importance, is considered in the paper as a research object.

3. Problem Statement

Basing on all abovementioned issues, the study of transient processes resulting from the enabling and

disabling the pump unit (PU) is essential for the analysis of transient modes in the trunk pipelines. Due to the changes in the performance of the pumping station (PS), when it is enabled or the separate units are disabled, the pressure in the pipe changes before and after oil-pumping station (OPS). Pressure change after disturbance source will affect the performance of the following OPS. In this task formulation, it is important to take into account the dynamic characteristics of two pipeline sections adjacent to OPS, in addition, at the beginning and at the end of pipeline sections the amount of the pressure change must be agreed with characteristics of related OPSs [4].

A discrete method of production control, as one of the methods to control the operation mode at PS, applied in domestic trunk pipelines of oil and oil products [1,5].

In this context, the paper analyzes the operation mode of trunk oil pipeline with multiple adjustable intermediate pumping stations basing on the proposed computational models for the study of dynamic processes in trunk pipeline systems (TP), and discrete regulation of OPC productivity [3].

4. Solution Methods

In this paper, double and discrete Laplace transformation is used as a mathematical device. Recurrence relations are applied in the transition from the image to the original functions [7]. It is known that the study of dynamic processes in the trunk pipeline is reduced to the solution of the equations of motion and continuity, with appropriate initial and boundary conditions [4].

One of the main objectives of management of oil transportation over a long distance in the present stage of development of pipeline transport is the optimization of the operating modes of TP. Obviously, to some extent it is provided by the circuits (methods) for regulating, features of regulatory devices, and their setting parameters. The choice of regulatory devices must be based on the processes in TP, when the mutual influence of OPS is taken into account.

Let's review the section of TP with two OPCs (Figure 1) in the regulation of operating mode of pumping stations with zero initial and boundary conditions:

$$\text{if } u_3=0 \quad \psi_3=0,$$

$$\text{if } u_3 = 1, u_2 = 0 \quad j_3 = j_2 = k_{42}\psi_3 - k_{52}\psi_2 + k_{62}\eta_2. \quad (1)$$

$$\text{if } u_2=1, u_1=0 \quad j_1=j_2=k_{41}\psi_2-k_{51}\psi_1+k_{61}\eta_1,$$

$$\text{if } u_1=1, j_1=B,$$

wherein ψ_i, j_i ($i=1, 2, 3$) denotes the relative change in pressure and flow in the pipeline; $k_{41}, k_{42}, k_{51}, k_{52}, k_{61}, k_{62}$ denote HC characteristics; η_i ($i=1,2$) denotes controlling impact of regulatory authorities.

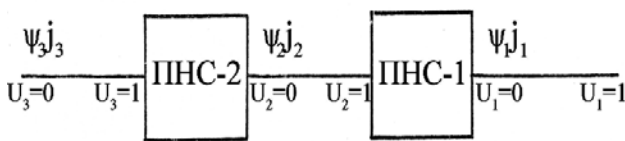


Figure 1. Structural scheme of the sections of TP with two OPSs

The boundary conditions given in the form (1) denotes that the interface conditions are specified in the PS

sections, i.e. the conditions, given by PS and regulatory devices on it, and a stepwise change in the flow at the end of the pipeline is specified.

In this case, the problem solution is reduced to the solution of equation systems

$$\begin{cases} -\frac{\partial \psi_i(u_i, t)}{\partial u_i} = k_2 j_i(u_i, t) + k_1 \frac{\partial j_i(u_i, t)}{\partial t}, \\ -\frac{\partial \psi_i(u_i, t)}{\partial t} = k_i \frac{\partial j_i(u_i, t)}{\partial u_i}, \text{ if } 0 \leq u_i \leq 1, i = 1, 2, 3 \end{cases} \quad (2)$$

which describe the dynamics in the corresponding sections of the trunk pipeline at the indicated zero and boundary conditions of the form (1).

In this case, the boundary conditions (1) in the operator form can be presented:

if $u_3=0$

$$\bar{\psi}_3(0, s) = 0$$

$$\bar{j}_3(1, s) = \bar{j}_2(0, s) = k_{42}\bar{\psi}_3(1, s) - k_{52}\bar{\psi}_2(0, s) + k_{62}\bar{\eta}_2(s),$$

if $u_3=1, u_2=0$

$$\bar{j}_3(1, s) = \bar{j}_2(0, s) = k_{42}\bar{\psi}_3(1, s) - k_{52}\bar{\psi}_2(0, s) + k_{62}\bar{\eta}_2(s), \quad (3)$$

if $u_2=1, u_1=0$

$$\bar{j}_1(0, s) = \bar{j}_2(1, s) = k_{41}\bar{\psi}_2(1, s) - k_{51}\bar{\psi}_1(0, s) + k_{61}\bar{\eta}_1(s),$$

if $u_1=1 \quad j_1 = \frac{1}{s} J.$

Solution of the equation system according to [3], under these initial and boundary conditions in the operator form is

$$\begin{cases} \bar{\psi}_3(u_3, s) = -\frac{sk_1 + k_2}{\gamma} sh\gamma u_3 \bar{j}_3(0, s) \\ \bar{j}_3(u_3, s) = ch\gamma_3 u_3 \bar{j}_3(0, s) \end{cases} \quad (4)$$

$$\bar{j}_3(0, s) = \frac{1}{ch\gamma_3} [k_{42}\psi_3(1, s) - k_{52}\psi_2(0, s) + k_{62}\eta_2(s)], \quad (5)$$

for the first section,

$$\bar{\psi}_2(u_2, s) = -sh\gamma u_2 \frac{sk_1 + k_2}{\gamma} \begin{bmatrix} k_{42}\psi_3(1, s) \\ -k_{52}\psi_2(0, s) \\ +k_{62}\eta_2(s) \end{bmatrix} + ch\gamma_2 u_2 \psi_2(0, s), \quad (6)$$

$$\bar{j}_2(u_2, s) = -sh\gamma_2 u_2 \frac{\gamma}{sk_1 + k_2} \psi_2(0, s) \quad (7)$$

$$+ ch\gamma_2 \times [k_{42}\psi_3(1, s) - k_{52}\psi_2(0, s) + k_{62}\eta_2(s)],$$

$$\bar{j}_3(1, s) = \bar{j}_2(0, s) \quad (8)$$

$$= k_{42}\psi_3(1, s) - k_{52}\psi_3(0, s) + k_{62}\eta(s),$$

for the second section,

$$\bar{\psi}_1(u_1, s) = -sh\gamma u_1 \frac{sk_1 + k_2}{\gamma} \begin{bmatrix} k_{41}\psi_2(1, s) \\ -k_{51}\psi_1(0, s) \\ +k_{61}\eta_1(s) \end{bmatrix} \quad (9)$$

$$+ ch\gamma u_1 \bar{\psi}_1(0, s),$$

$$\bar{j}_1(u_1, s) = -sh\gamma u_1 \frac{\gamma}{sk_1 + k_2} \psi_1(0, s) \quad (10)$$

$$+ ch\gamma u_1 \times [k_{41}\psi_2(1, s) - k_{51}\psi_1(0, s) + k_{61}\eta_1(s)],$$

$$\bar{j}_1(0, s) = \bar{j}_2(1, s) = k_{41}\psi_2(1, s) - k_{51}\psi_1(0, s) + k_{61}\eta_1(s), \quad (11)$$

The originals of these functions are defined in the image table [3,10]. For example, the function original $\psi_3[n]$,

$$\Psi_3[n] = \sqrt{k_1 k_3} \cdot k_{42} \left(\begin{array}{l} \sum_{m=\lambda(1+u_3)}^n k_{32}[n-m]\Psi_3[1, n] \\ - \sum_{m=\lambda(1+u_3)}^n k_{32}[n-m]\Psi_3[1, n] \end{array} \right)$$

$$+ \sqrt{k_1 k_3} \cdot k_{52} \left(\begin{array}{l} \sum_{m=\lambda(1+u_3)}^n k_{32}[n-m]\Psi_2[0, n] \\ + \sum_{m=\lambda(1+u_3)}^n k_{31}[n-m]\Psi_2[0, n] \end{array} \right)$$

$$- k_{62} \sqrt{k_1 k_3} \left(\begin{array}{l} \sum_{m=\lambda(1+u_3)}^n k_{32}[n-m]n_2[m] \\ + \sum_{m=\lambda(1+u_3)}^n k_{31}[n-m]n_2[m] \end{array} \right)$$

$$- \sum_{m=\lambda}^n k_{30}[m]\Psi_3[n-m] - \sum_{m=0}^n \Psi_3[m]I[n-m]$$

$$\bar{k}_i[n] = \begin{cases} 0, & \text{if } m < \theta \lambda \\ e^{-\frac{\alpha_3 T_3}{2}} \\ + a\theta \lambda \sum_{m=\theta \lambda}^n e^{-\frac{\alpha_3 m T_3}{\lambda}} I_1 \left(\frac{\alpha_3 T_3}{\lambda} \sqrt{m^2 - (\theta \lambda)^2} \right) \\ \sqrt{m^2 - (\theta \lambda)^2} \end{cases}; m > \theta$$

wherein

$$i = 30, \quad \theta = 1$$

$$i = 31, \quad \theta = (1 - u_3)$$

$$i = 32, \quad \theta = (1 + u_3)$$

k_{42} , k_{52} , k_{62} denote constant coefficients.

These functions have a common characteristic equation of

$$\Delta = \gamma sh^3 \gamma + \left[\frac{\gamma^2}{(sk_1 + k_2) \cdot k_{41}} + (sk_1 + k_2) k_{41} \right. \\ \left. + (sk_1 + k_2) \times \frac{k_{41}}{k_{42}} k_{52}(s) \right. \\ \left. + (sk_1 + k_2) k_{51}(s) \right] \cdot \\ \cdot sh^2 \gamma ch \gamma + [k_{52}(s) + k_{51}(s) + k_{41}] \frac{\gamma}{k_{42}} sh \gamma ch^2 \gamma \quad (12) \\ + \frac{sk_1 + k_2}{k_{42}} k_{51}(s) k_{52}(s) ch^3 \gamma,$$

Table 1. Results of experimental calculations

№	(τ)c	OPS-1		OPS-2				x ₂ +15 km		x ₂ +57 km	
		input MPa	outlet MPa	input		outlet		calc.	exp.	calc.	exp.
				calc.	exp.	calc.	exp.				
1	0	0,4	3,35	0,05	0,05	2,7	2,7	3,6	3,6	1,68	1,68
2	3	0,4	3,35	0,62	0,64	2,164	2,28	3,6	3,6	1,68	1,68
3	5	0,4	3,35	0,94	1	1,98	2,0	3,6	3,6	1,68	1,68
4	13,6	0,4	3,35	1,15	1,2	1,65	1,7	3,51	3,42	1,68	1,68
5	16	0,4	3,35	1,18	1,215	156	1,69	3,23	3,16	1,68	1,68
6	18	0,4	3,35	1,21	1,23	1,555	1,68	2,89	2,8	1,68	1,68
7	24,5	0,4	3,35	1,216	1,26	1,55	1,66	2,56	2,68	1,68	1,68
8	32,7	0,4	3,35	1,25	1,34	1,54	1,62	2,58	2,624	1,68	1,68
9	42,7	0,4	3,35	1,333	1,383	1,49	1,52	2,565	2,555	1,61	1,68
10	48	0,4	3,35	1,35	1,37	1,495	1,513	2,555	2,511	1,61	1,68
11	51,8	0,4	3,35	1,375	1,38	1,465	1,50	2,53	2,48	1,64	1,60
12	53,5	0,4	3,35	1,378	1,383	1,463	1,499	2,49	2,478	1,51	1,4
13	59	0,4	3,35	1,382	1,39	1,461	1,494	2,48	2,47	1,23	1,12
14	67,3	0,4	3,35	1,395	1,41	1,46	1,49	2,47	2,46	1,15	1,04
15	78,2	0,4	3,35	1,399	1,4	1,45	1,48	2,455	2,44	1,015	0,98
16	89	0,45	3,42	1,4	1,38	1,489	1,48	2,443	2,434	0,985	0,944
17	100	0,49	3,68	1,41	1,39	1,449	1,45	2,441	2,44	0,94	0,92
18	125	0,57	3,93	1,413	1,42	1,449	1,45	2,44	2,472	0,935	0,912
19	144	0,61	3,98	1,412	1,42	1,441	1,45	2,44	2,456	0,91	0,888

For the evaluation of the developed computational model of transient processes in TP [3], the change in pressure was calculated at the input and outlet of disabled OPS, next NPC, as well as at various sections by using the experimental data obtained on operating pipelines. For example, Figure 2 shows the calculated and experimental curves of pressure changes at the input and the outlet of disabled OPS. The results of the pressure change at the input and outlet of disabled OPS -2, at the input and outlet of OPS-1, as well as at 15 and 57 km from OPS-2 flow are summarized in Table 1 and shown in Figure 3. The results of calculations of pressure change in the disabled OPS are given in Figure 3.

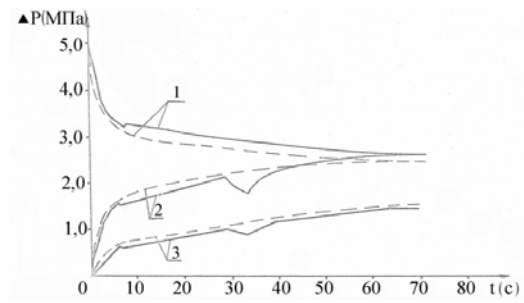


Figure 2. Calculated and experimental curves of pressure change in the pipeline

1,2 - respectively pressure change curves at the outlet and the input of the station. 3 - curves of pressure changes in the intermediate point of the path (solid line – experimental, dashed - calculated).

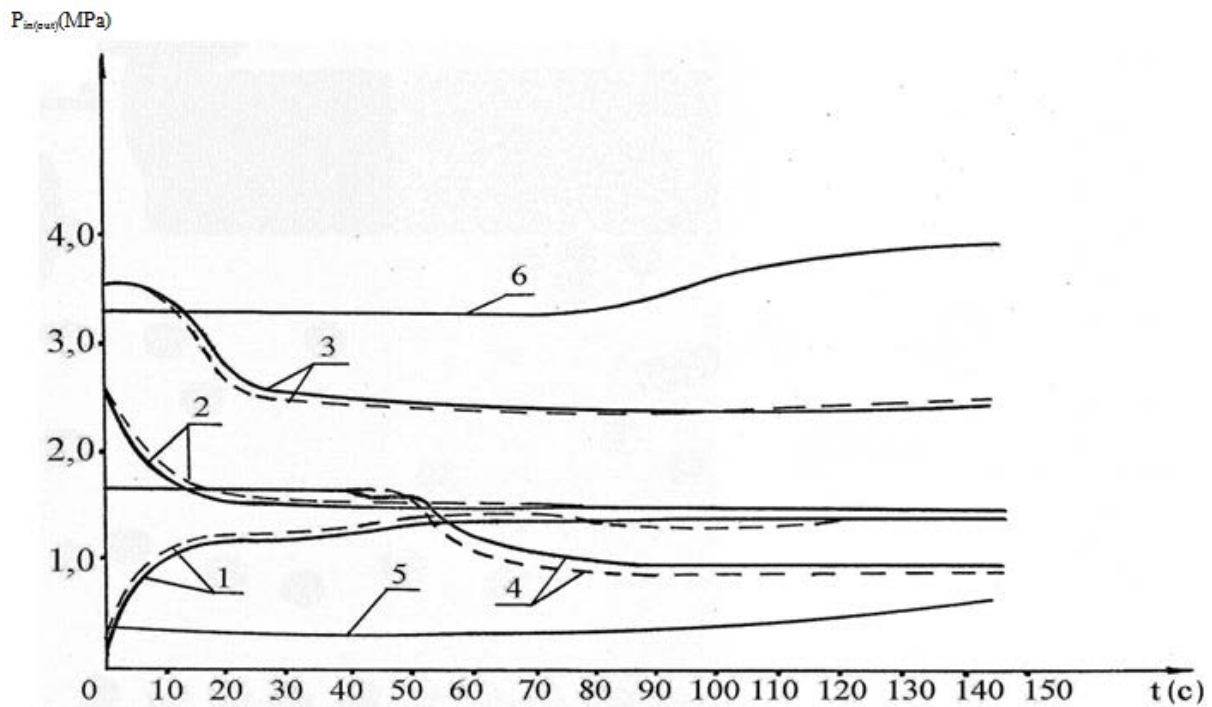


Figure 3. The pressure change curves at the inlet (2) and output (1) OPS (Solid lines experimental, dashed calculated)

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