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Automated systems for main oil pipelines diagnostics and control

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Abstract. The issues of diagnostics of the technological objects operation of the main oil pipeline and control of their operation modes using automated systems are investigated. The systems and methods for diagnostics and determination of oil leakage from main oil pipelines are studied. A method for remote detection of oil leakage from main oil pipelines is described. SCADA systems that allow monitoring changes in all pumping technological parameters in real mode are described. The mathematical formulation of the problem of controlling the operating modes of technological objects of the main oil pipeline in the conditions of indistinctness of some part of the initial information is formalized and obtained. Based on the modification of the idea of the principle of the main criterion, a heuristic method for the effective solution of the obtained fuzzy problem has been developed.

1. Introduction

Trunk oil pipelines are complex hydraulic, highly mechanized and automated systems that are distributed over fairly large distances. Such oil pipeline systems are equipped with powerful pumping stations for pumping oil and have a linear part, as well as means of technological communication, telemechanics and automation, fire-fighting devices [1, 2]. It should be noted that oil heating stations are mandatory for “hot” oil pipelines intended for pumping high-viscosity, i.e. highly paraffinic oils [3].

The main elements of the oil pipeline system, i.e. process units of the oil pipeline are shown in the figure below (figure 1). Currently, in the oil pumping industry, the issues of diagnostics of main oil pipelines and effective management of the oil transportation processes through pipelines with minimization of the impact of the main technological objects of the oil pipeline on the environment are urgent problems of science and technology [4-6].

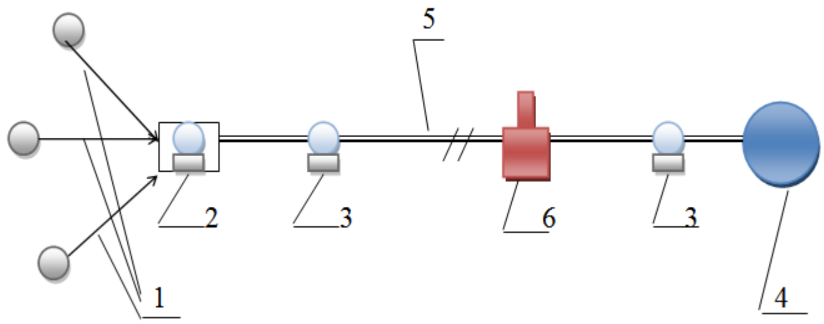

Figure 1. Main oil pipeline technological objects. 1 – supply pipelines that connect oil sources with the head structures of the pipeline; 2 – head station for oil pumping; 3 – intermediate oil pumping stations; 4 – terminal points for receiving oil; 5 – linear part of the pipeline, i.e. the pipeline itself; 6 – oil heating stations for "hot" pipelines.

The aim of this work is to study automated systems for diagnosing the state of technological objects of a main oil pipeline and controlling the processes of oil transportation through pipelines. Also, the work will formulate the task of controlling the operating modes of the main objects of the oil pipeline in a fuzzy environment and propose a method for solving it based on a heuristic approach.

2. Diagnostics of technological objects of main oil pipelines and effective control of their operating modes in a fuzzy environment

2.1. Diagnostic and management systems for oil transportation facilities via main oil pipelines

The quality of the diagnostic system and automated control systems (ACS) depends on the metrological qualities of the measuring instruments, on the statistical and dynamic properties of the control means and measuring mechanisms. In the general case, the state of the object is determined by the output parameters – Y, which, in turn, are determined from the value of the input parameters X and control actions U. External, deviating influences F negatively affect the process of object control. Control actions U, are aimed at compensating for linkages, i.e. deviations caused by F. In automated control systems for main oil pipelines, fluid pressure or change in the output value, for example, productivity, are often used as control actions U. As the main means of obtaining information entering the ACS, i.e. to measure the values of X, Y and U, sensitive devices are used, namely measuring instruments and information-measuring systems.

The structure of modern automated control systems includes diagnostic and forecasting systems. Currently, technological objects are equipped with various devices that ensure timely detection of the violation of the processes occurring in them. In work [7], a system for diagnostics and determination of oil leakage from trunk pipelines is considered. This diagnostic system is based on the following principle: at the boundaries of the observed areas, a vacuum wave is recorded, which occurs when a leak occurs. This provides a high sensitivity of the method (1.5–3% Qnom) and a low error in determining the location of the leak. The method requires constant monitoring of pressures. When this method is used under conditions of discontinuity of the flow in the pipe, the signal is almost completely isolated in the gravity section and the possibility of its registration is excluded. And the presence of foreign objects in the pipe, tie-ins or sharp turns generates reflected waves that distort the shock wave front, which also reduces the percentage of registrations. A method for monitoring based on a 2-level data exchange scheme by means of an intelligent device with the ability to self-adjust to the specifics of the controlled object is proposed. Its use makes it possible to reduce the number of false alarms of the pumping process control system, to increase the correctness of transmission and the efficiency of information processing due to the minimum number of used technical means. Thus, the known monitoring methods of leak detection systems are based on the comparison of the controlled pumping parameters and the calculated ones, which are obtained by simulating the process in real time. Accordingly, the reliability of the conclusions about the presence of a leak largely depends on the pipeline models used.

A method for remote detection of oil leaks from oil trunk pipelines is known [8]. This method includes aerial photography of the thermal field of the pipeline route, determination of threshold values of brightness, determination of the location of local areas with anomalous temperature. In this method, the location of the leak is determined by the location of the area with an anomalous temperature, for which the logarithm of the relative image brightness for the first wavelength differs from the average value for the entire controlled area by a predetermined threshold value, and the logarithms of the relative image brightness for three waves make up the proportion (1±0,2):(1,4±0,2):(1,2±0,2).

The method of controlling the magnitude of the pressure of the liquid is that a surface electromagnetic wave is excited from one end of the pipeline, and its intensity is recorded at the end point. By a sharp change in intensity, one can judge about a violation of the continuity of the transported product, the fact that a gas-air accumulation or other foreign inclusion has formed in it. In this method, on the basis of time indicators, the location and volume of foreign matter is determined. However, this method gives significant errors due to the ambiguity of the object's characteristics: a change in the regime and shape of the fluid flow.

If the propagation of high pressure waves has significant steepness and amplitudes that exceed the calculated values, then it is recommended to apply pipeline rupture protection systems. The principle of operation of the protection system is that when any intermediate station is disconnected, an electrical signal is transmitted to the previous station via the communication channel, while the discharge pressure setting is reduced. As a result, a pressure decrease wave is sent towards the pressure increase wave, and at intermediate points of the route the pressure does not exceed the maximum allowable. The disadvantage of the advanced signal protection system is the dependence on the reliability of the communication channel. In addition, only half of the area adjacent to the previous one from the discharge side of the station falls within the protection coverage. The IMS group of companies has developed and implemented pressure wave smoothing systems, as well as water hammer protection systems, which significantly increase the throughput, resource and reliability of pipeline systems. The principle of operation of the systems is based on the timely discharge of the working fluid through the control valves, the flow through which is controlled and adjusted by the control system. These systems are successfully used in JSC Baltnefteprovod, JSC Trans-Siberian Trunk Oil Pipelines, etc.

Currently, SCADA systems have become widespread, providing effective management of the operational section of the main pipeline. In real time, SCADA systems allow monitoring changes in all technological parameters of pumping. The use of modern SCADA technologies, telemechanics and automated control systems makes it possible to solve the problems of functional diagnostics of complications of technological modes of oil pipelines. In the world market, the following dispatch control and data collection systems are most popular, i.e. SCADA systems FactoryLink (manufacturer USDATACo, USA), Genesis (Iconics, USA), Sitex (JadeSoftware, England), TraceMode (AdAstraResearchGroup Ltd., Russia), SIMATICWinCC (SiemensAG, Germany), etc.

Automated control systems are designed and created to correctly monitor the condition of the pipes and control the processes occurring during the operation of the pipeline. In these systems, the initial data for assessing the condition of the pipeline are determined based on:

- external and internal pipe diagnostics and metallographic studies;
- collection of information on the parameters of the transported medium, obtained using integrated automated control systems at the level of the compressor station, line production control or oil and gas transportation enterprise as a whole;
- analysis of cartographic material and design and construction documentation.

External diagnostics of pipelines, in particular, makes it possible to assess the displacement of pipes from the design location as a result of natural soil movement and thermal deformations of pipelines. To design a control system, a SCADA system is used or the introduction of its own high-level language interpreter into the design systems, which significantly increases the flexibility of the system, as well as simplifies the processes of constant monitoring and control. Efficiency of decision making is ensured by introducing its own WEB and WAP interfaces into the system.

A more promising direction in the development of control systems for trunk pipeline facilities is associated with the construction of *intelligent control systems and intellectualized decision support systems*. At the same time, the method of *fuzzy control* with forecasting allows for a well-balanced assessment of management objectives through the use of knowledge, experience and intuition of experts. The controllers installed at the pumping station from time to time estimate during pumping the deviation of the real parameters from the model ones and form control commands in the system to ensure the given technological pumping mode. The use of a multivariable adaptive model makes it possible to increase the efficiency of decision-making in emergency situations, to track trends in the development of processes in pipelines, it is clear for the user to interpret the parameters of the pumping process collected by the SCADA system and to present the diagnostic results for analysis in a convenient form. Despite the obvious advantages and prospects, the development of new SCADA systems requires significant material and time costs, which forces the use of existing tools.

2.2. The problem of controlling the operating modes of an oil pipeline technological objects in a fuzzy environment and a method for its solution

Let us formalize and present a mathematical formulation of the problem of controlling the operating modes of a technological object of a main pipeline in a fuzzy environment and propose a method for solving the obtained problem based on the experience and intuition of a decision-maker (DM). In general, such a problem can be formalized as follows [9]:

Let $\mu_0(x)=(\mu_0^1(x),...,\mu_0^m(x))-$ vector of normalized criteria evaluating the efficiency of the main pipeline system; $\varphi_q(x)\tilde{\geq} b_q,\ q=\overline{1,L}-$ fuzzy restrictions; $\mu_q(x),\ q=\overline{1,L}-$ membership functions that estimate the degrees of fulfillment of fuzzy constraints [10]. Suppose with the participation of experts and decision makers, the weight vectors of the importance of criteria $\gamma=(\gamma_1,...,\gamma_m)$ and restrictions are determined $\beta=(\beta_1,...,\beta_L)$.

Then the problem of making decisions in a fuzzy environment to control the operating modes of technological objects of the oil pipeline in general form can be written in the following form [11]:

$$\max_{x\in X}\mu_0^i(x),\ i=\overline{1,m} \tag{1}$$

$$X=\{x:\arg\max_{x\in\Omega}\mu_q(x),\ q=\overline{1,L}\} \tag{2}$$

To concretize the given problem (1)–(2) based on the modification of the main criterion method for fuzziness in the case of m criteria and L fuzzy constraints, we obtain the problem:

$$\max_{x\in X}\mu_0^1(x), \tag{3}$$

$$X=\left\{x:x\in\Omega\wedge\arg\left(\mu_q(x)\geq\mu_q^R\right)\wedge\arg\left(\mu_0^i(x)\geq\mu_{0R}^i\right),\ q=\overline{1,L},\ i=\overline{2,m}\right\}. \tag{4}$$

The solution to problem (3)–(4) depends on the boundary values of constraints and criteria $\mu_1^R,...,\mu_L^R;\ \mu_{0R}^2,...,\mu_{0R}^m$, that are determined by the decision maker and experts [12].

The main points of the proposed heuristic method based on the adaptation of the principle of the main criterion for solving problem (3)–(4);

1. For local criteria and fuzzy constraints, introduce a number of priorities: $I_C=\{1,...,m\}$ and $I_R=\{1,...,L\}$. In this case, the main criterion should have priority1;

2. With the involvement of decision makers and experts, determine the boundary values for the criteria transferred in the restriction $\mu_{0R}^{i}, i=\overline{2,m}$ and for the restrictions $\mu_q^R, q=\overline{1,L}$;

3. On the basis of expert judgment, determine term-sets and build membership functions that assess their degree of performance: $\mu_q(x) \geq \mu_q^R, q=\overline{1,L}$;

4. Solving the problem of maximizing the main criterion $\mu_0^1(x)$ (3) under the condition of imposed restrictions on the sets X (4) and determining the current solutions: $x(\mu_{0R}^i, \mu_q^R)$; $\mu_0^1(x(\mu_{0R}^i, \mu_q^R)),..., \mu_0^m(x(\mu_{0R}^i, \mu_q^R))$; $\mu_1(x^*(\mu_{0R}^i, \mu_q^R)),..., \mu_L(x^*(\mu_{0R}^i, \mu_q^R)), i=\overline{2,m}, q=\overline{1,L}.$

5. Presentation of the obtained decisions of the decision maker. If the solutions do not satisfy, then go to step 6. Otherwise, the decision maker changes the values μ_{0R}^i, μ_q^R and to improve the solution return to step 3;

6. Finding the final solutions, selected by the decision maker as the best: $x^*(\mu_{0R}^i, \mu_q^R)$ – the optimal values of the input and operating parameters of the object, which provide the effective values of the criteria $\mu_0^1(x^*(\mu_{0R}^i, \mu_q^R)),..., \mu_0^m(x^*(\mu_{0R}^i, \mu_q^R))$ and the maximum degree of fulfillment of fuzzy constraints $\mu_1(x^*(\mu_{0R}^i, \mu_q^R)),..., \mu_L(x^*(\mu_{0R}^i, \mu_q^R))$.

For a reasoned choice by the decision maker of the boundary values of the criteria and constraints: μ_{0R}^i, μ_q^R, $i=\overline{2,m}, q=\overline{1,L}$ you can organize a dialog procedure for analysis and assignment μ_{0R}^i, μ_q^R you can create dialog procedures for selecting new values.

3. Discussion of results

According to the results of the study, it can be established that when designing a control system, the use of a SCADA system and a high-level language interpreter can significantly increase the flexibility of the system, as well as simplify the processes of constant monitoring and control. It has been determined that the efficiency and quality of the systems for diagnosing the state of control of the operating modes of technological objects of the main oil pipeline and automated control systems for oil pumping processes depend on the metrological qualities of measuring instruments, on the statistical and dynamic properties of control devices and measuring mechanisms.

Since the functioning of real technological objects of main oil pipelines can often be characterized by the fuzziness of some part of the initial information, when setting and solving control problems for these objects, one has to take into account and use fuzzy information in the form of knowledge, experience and intuition of decision makers and expert specialists. This approach to solving a fuzzy control problem allows you to get more efficient and adequate solutions in a fuzzy environment.

4. Conclusion

The state of diagnostic systems for controlling the operating modes of technological objects of main oil pipelines has been investigated. The systems and methods of diagnostics and determination of oil leakage from main oil pipelines are analysed, highlighting their advantages and disadvantages. SCADA systems are considered that provide effective control of the operational section of the main pipeline and monitor changes in all technological pumping parameters in real time. A promising direction in the development of control systems for objects of main pipelines has been determined to build intelligent control systems that, through the use of knowledge, experience and intuition of experts and decision makers, ensure an effective decision.

The novelty of the work lies in the fact that the formulation of the problem of controlling the modes of operation of objects in a fuzzy environment has been obtained and an effective method has been developed for its solution based on the modification of the principle of the main criterion. Since many technological objects of the oil pipeline operate in conditions of indistinctness of the initial information, the proposed approach to solving the control problem in a fuzzy environment has practical significance.

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