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Intellectual Control of Dangerous States of the Facilities of Main Hydrocarbon Transport Systems in Adaptive Expert Systems

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Abstract. The work deals with the development of methods for assessing the reliability of oil and gas equipment and systems for adaptive decision support systems. At the Department of Hydrocarbon Transportation, studies are underway to create decision support systems with predictive, warning and reliability assessment functions. The proposed methodology can be used for adaptive expert systems for monitoring reliability in real time. The technique allows identifying the state of the technological facility and predicting the probabilities of parametric failure by the given criteria. The proposed method has been tested and can be used when estimating the reliability of oil and gas pipeline technical systems.

1. Introduction

A complex of collaborative intelligent technological management of reliability and efficiency of oil and gas systems (CI-TREMS) is a fundamentally new technology of intelligent instrumental neural network engineering control developed at the Department of Hydrocarbon Transport for forecasting and preventing contingencies, incidents and accidents, optimization and ensuring the effectiveness of technical solutions for the management of industrial processes. CI-TREMS is modular and multitasking, flexible and adaptive, it is based on the theory of neural network programming, reliability theory, cybernetics, system analysis, statistics and probability, etc. Moreover, currently the issues of ecology and noosphere culture in oil and gas engineering are undoubtedly relevant and acquired a special significance at various facilities from Siberia to the Arctic [1-9] and the existence of such systems in hazardous enterprises is a necessity.

The author's research focuses on the development of methodological support for this anticipatory monitoring and control system which includes a set of algorithms, techniques, mathematical models. One of the important tasks is monitoring of dangerous states of technical systems and the probability of finding them in real time by dispatching data.

The problem of ensuring the reliability and safety of hydrocarbon transportation facilities is very time-consuming and multifaceted. Solutions of individual problems of ensuring reliability and optimizing repair work at oil and gas facilities and in the engineering sphere are described at different times in numerous works of well-known scientists: Yasin E.M., Gubin V.E., Abuzova F.F., Berezin V.L., Tugunov P.I., Novoselov V.F., Lurie M.V., Korolenok A.M., Sukharev M.G., Kolotilov Yu.V., Krapivskiy E.I., Kuchumov R.Ya., Shabarov A.B., Gulkov A.N., Gumerov A.G., Moiseyev B.V., Chekardovsky M.N., Ivantsov O.M., Moldavanov O.I., Yakovlev E.I., Shibnev A.V., Vasilyev G.G.,



Prokhorov A.D., Antipyev V.N., Aginey R.V., Rashchepkin K.E., Mazur I.I., Pisarevsky V.M., Polyakov V.A., Shalay V.V., Gladenko A.A., Mustafin F.M., Korshak A.A., Zemenkov Yu.D., Shammazov A.M., Mastobaev B.N., Nechvalya A.M., Korobkov G.E. [1, 2, 9-23].

Let's consider some issues related to the modernization of the system of technical regulation in the field of ensuring safety of hazardous production facilities in 2018. Theoretical and practical issues of solution provide for individual work with each technical system [1,2].

The new requirements in the field of industrial safety were approved on January 24, 2018. The order of the Federal Service for Ecological, Technological and Nuclear Supervision No. 29 in the oil and gas industry started a new stage - the safety manual "Methodological recommendations on the classification of man-made events in the field of industrial safety at hazardous production facilities of the oil and gas complex" was approved [10].

Technogenic events in the field of industrial safety are now recommended to be classified on the basis of technological features of the facility, signs of the realization of the hazard of accidents, the severity of consequences into four levels of danger:

Level 1 - accident;

Level 2 - incident;

Level 3 - premise to the incident (hereinafter - premise);

Level 4 - violations in the system of industrial safety management or deviations of technological parameters, but without exceeding the maximum permissible values, including those registered by remote control.

A modern classification of hazardous facilities requires new approaches and technology of control, differentiation and management of events. For example, it is now recommended to evaluate the parameters for an anthropogenic event using models corresponding to the specifics of the facility.

Let us consider the features of constructing a model on the basis of the theory of interval estimates with the use of parametric methods.

2. Materials and methods

Let us consider the basic model, most simply applicable under operation conditions for oil and gas complex facilities. According to the model proposed by the author for the new standard [8], for all types of technological equipment, 5 levels of functioning and 5 types of states are assumed. The most dangerous level is the first, characterized by an emergency state, the safest - the 5th - is normal functioning within the parameters established by the regulations and characterized by stationarity.

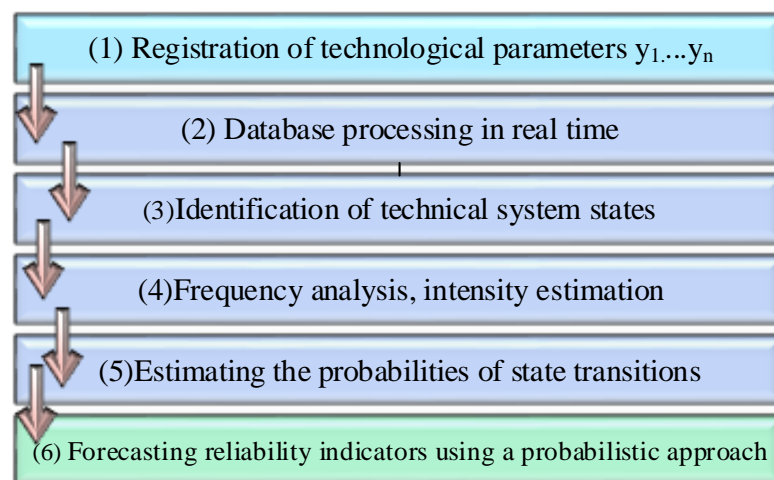
The process of transitioning to the higher level is characterized by undesirable events and occurs with intensities λ_{ij} , reaching critical operating levels, where i is the previous state, and j is the following. A lot of operable states belong to the set $E+$, if the system loses its operability, the state belongs to the set $E-$. Maintenance is considered as a recovery procedure with intensity μ_{ji} . Under the normal operation conditions, many parameters characterizing the operation of the system $y_i(t)$ are technologically regulated and belong to the range of admissible values $y_i(t) \in Y_{iadd}$. In case the registered parameter reaches the critical level according to the regulations, but not providing for stopping the technological process of transport, the parameter belongs to the range of critical values $y_i(t) \in Y_{icr}$. The technological and mathematical formulations of states are presented in Table 1.

It is proved that statistical distributions of failures of complex equipment and systems are not limited to an exponential type of distribution, but require a refinement in real time [1,2,3]. In this case, the methods for assessing the risks of events require a fairly accurate prediction of events. In the model proposed by the author, λ_{ij} , μ_{ji} are variables that are assessed automatically in real time by statistical methods.

Table 1. Identification of states during operation.

Levels of hazard	stateDescription	Mathematical definition
Level 5	Normal operating parameters (within the limits of the regulations)	$y_i(t) \in E_+$ $y_i(t) \in Y_{add}$
Level 4	Violations in the system of industrial safety management or deviations of technological parameters	$y_i(t) \in E_+$ $y_i(t) \in Y_{icr}$
Level 3	Premise. Critical level of the parameter, contingency	$y_i(t) \in E_+$ $y_i(t) \in Y_{icr}$
Level 2	Incident. Parameter failure level, any parameter exceeding the permissible limits	$y_i(t) \in E_-$
Level 1	Accident Parameter failure level, consequences, damage	$y_i(t) \in E_-$

The general algorithm for the functioning of the identification system is shown in Fig. 1. Steps 1 and 3 provide for the initial processing of information and state identification. Such identification can be realized using neural network technologies, for example, using Kohonen networks or multi-layer neural networks.

**Figure 1.** General algorithm for reliability analysis based on the probabilistic approach and parametric identification.

Consider the ordered set of states of the system S_1, S_2, S_3, S_4, S_5 . The features of the model consist in the transition between S_k states only through the neighboring states. To build the model, we suppose that all event streams that determine the intensity of transitions are the simplest ones with intensities $\lambda_{k,k+1}$ and reconstructions $\mu_{k+1,k}$. According to the graph presented in Fig. 2, we will compose and solve algebraic controls for the limiting probabilities of states. We note that the existence of these probabilities depends on the possibilities of transitioning from each state to each other and the finiteness of the number of states.

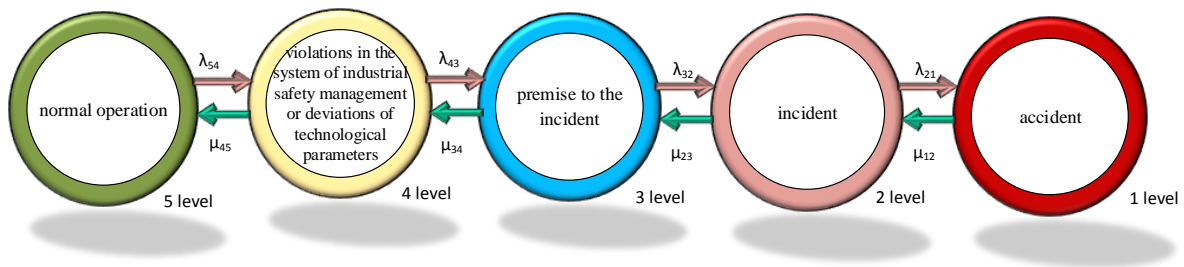


Figure 2. Graphical representation of the evolution of technological facility hazard levels.

In accordance with the provisions of the theory of mortality and reproduction, we will perform a mathematical description of the established model:

$$\lambda_{54}p_5 = \mu_{45}p_4, \quad (1)$$

for state 5

$$(\lambda_{43} + \mu_{45})p_4 = \lambda_{54}p_5 + \mu_{34}p_3, \quad (2)$$

$$\lambda_{43}p_4 = \mu_{34}p_3, \quad (3)$$

We obtain a system of equations for the limiting probabilities of the proposed model:

$$\begin{cases} \lambda_{54}p_5 = \mu_{45}p_4 \\ \lambda_{43}p_4 = \mu_{34}p_3 \\ \lambda_{32}p_3 = \mu_{23}p_2 \\ \lambda_{21}p_2 = \mu_{12}p_1 \end{cases} \quad (4)$$

To solve the system, we need a normalization condition:

$$p_0 + p_1 + p_2 + p_3 + p_4 + p_5 = 1 \quad (5)$$

Solving the system, we get:

$$p_5 = \left(1 + \frac{\lambda_{54}}{\mu_{45}} + \frac{\lambda_{43}}{\mu_{34}} \frac{\lambda_{54}}{\mu_{45}} + \frac{\lambda_{32}}{\mu_{23}} \frac{\lambda_{43}}{\mu_{34}} \frac{\lambda_{54}}{\mu_{45}} + \frac{\lambda_{21}}{\mu_{12}} \frac{\lambda_{32}}{\mu_{23}} \frac{\lambda_{43}}{\mu_{34}} \frac{\lambda_{54}}{\mu_{45}} \right)^{-1} \quad (6)$$

$$p_4 = \frac{\lambda_{54}}{\mu_{45}} p_5, \quad (7)$$

$$p_3 = \frac{\lambda_{43}}{\mu_{34}} \frac{\lambda_{54}}{\mu_{45}} p_5, \quad (8)$$

$$p_2 = \frac{\lambda_{32}}{\mu_{23}} \frac{\lambda_{43}}{\mu_{34}} \frac{\lambda_{54}}{\mu_{45}} p_5, \quad (9)$$

$$p_1 = \frac{\lambda_{21}}{\mu_{12}} \frac{\lambda_{32}}{\mu_{23}} \frac{\lambda_{43}}{\mu_{34}} \frac{\lambda_{54}}{\mu_{45}} p_5. \quad (10)$$

Dependencies (6-10) are designed to determine the probabilities of finding in specific states of a technical system, from a pumping-power unit to a station as a whole or a section of a linear part. The advantage of this model is the ease of use, regardless of the structural model of the facility by registered parameters in real time. It is worth noting that the model is complicated and used with some peculiarities in the case of identification of the Weibull distribution or other distributions with variable failure intensities.

More complex models using different types of distribution are presented by the author in [1,2].

3. Conclusion

Thus, using the presented calculation technique, it is possible to predict the reliability by the dynamics of the probability of being in dangerous states, the intensity of parametric failures.

The algorithm and methodology are designed for functioning within the framework of an adaptive expert control system for reliability of energy-mechanical equipment of oil and gas pipelines. When the system operates in real time and determines the exact type and parameters of failure distribution (physical or parametric), the results can have different accuracy, complexity, and a list of diagnosed indicators. Based on the monitoring results of the technological facility, not only management solutions can be adopted, but also solutions on constructive system improvement. The models and algorithms are tested by the author and implemented in the form of software. Application of the technology of intellectual control and forecasting in real time allows optimizing labor and material resources to ensure the reliability of elements and the facility as a whole.

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