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Modeling Parameters of Reliability of Technological Processes of Hydrocarbon Pipeline Transportation

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Abstract. On the basis of methods of system analysis and parametric reliability theory, the mathematical modeling of processes of oil and gas equipment operation in reliability monitoring was conducted according to dispatching data. To check the quality of empiric distribution coordination , an algorithm and mathematical methods of analysis are worked out in the on-line mode in a changing operating conditions. An analysis of physical cause-and-effect relations mechanism between the key factors and changing parameters of technical systems of oil and gas facilities is made, the basic types of technical distribution parameters are defined. Evaluation of the adequacy the analyzed parameters of the type of distribution is provided by using a criterion A.Kolmogorov, as the most universal, accurate and adequate to verify the distribution of continuous processes of complex multiple-technical systems. Methods of calculation are provided for supervising by independent bodies for risk assessment and safety facilities

1 Introduction

In modern conditions of operation of technical systems of oil and gas industry an important task is to ensure the safety of objects by selecting the optimal operating conditions, timely and high-quality maintenance and repair [1,2,4,7,8]. The current system of assessing the reliability, based on the statistical evaluation of reliability index does not fully meet modern requirements [9], since, by definition, involves the fact of the occurrence of failure [11,13-16,19,20]. Operation of oil and gas companies provide preventive maintenance system with conditions to minimize any incidents, so the statistical information is unsuitable for classical reliability analysis. On-line monitoring models of reliability of the equipment and technologies of predicting failures are taking particular relevance and therefore require modern methods of analysis of the parametric reliability [10,17,18]. For high-quality mathematical reliability evaluation and selection of models and techniques, it is necessary to observe the main stages of preliminary data analysis based on the application of

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engineering data; graphical methods of estimation; nonparametric methods and evaluation criteria to determine the physical and mathematical models of reliability and features techniques. To obtain an adequate model of reliability it is very important to choose the type of distribution of failures or events corresponding to the actual, which depends largely on the accuracy of the results.

2 Methodological foundation

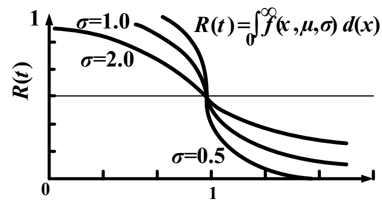
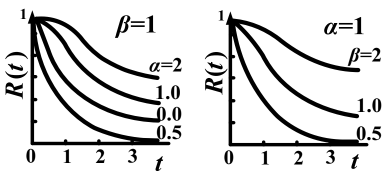
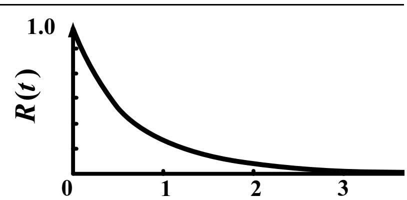
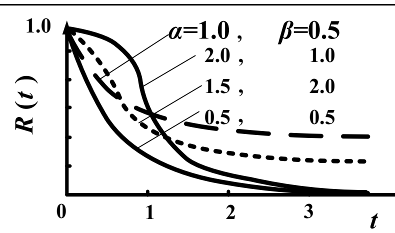
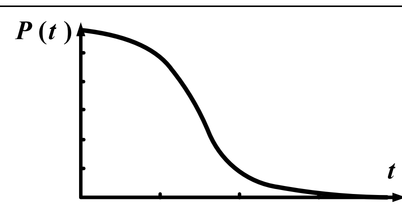
We'll define the aspects of mathematical modeling of processes for monitoring the reliability of oil and gas equipment according to dispatching data. To check the quality coordination of the empirical distribution agreement with the hypothetical use of fitting criteria. The most common and rather simple criteria are χ - square, Kolmogorov-Smirnov criteria. Kolmogorov-Smirnov test is applied in cases where the estimated distribution is continuous (particularly at tests for reliability).

Analysis of publications suggests that the following types of distributions are among the many most applicable distribution for parameters and characteristics of reliability of technical systems: exponential, normal, Weibull, Rayleigh, and logarithmic.

In most cases, gradual failures of complex equipment are subjected to the normal law; the laws of exponential form are accepted in the simulation of sudden failures.

Despite the fact that in some cases the use of the exponential law allows to obtain a good approximation, to construct correct models in any particular case justification is required. It should be noted that the use in the calculation of the reliability of the exponential distribution law is possible only under the condition that the failure rate is constant, i.e. the system is operated in the normal operation period. In other cases, it is necessary to use other laws, although this fact complicates the task of determining reliability. Analysis of the physical laws of cause and effect relationships between the key factors and changes in parameters of engineering systems of oil and gas facilities [3,4,5,6] has allowed to identify the main types of distributions - the most suitable are the normal law and Weibull. The normal law can be seen as the limit to which other laws approach with common typical conditions. The law allows describing parameters that are formed in real conditions under the influence of numerous mutually independent and weakly dependent factors or are the sum of some random variables. Distribution gives the opportunity to describe wearing processes and change of properties of the system taking into account working conditions (loading, speed, and temperature), personnel qualification, quality of material, hardness, purity of surface, precision manufacturing etc. When sudden changes of operating conditions occur (overload, violation and incomplete execution of modes, changing the equipment and parts for repairs etc.), application of the normal aw is not correct. The advantage of Weibull theoretical distribution law is shown in a model of a "weak chain"when the system consists of a group of independent elements, where each failure leads to the failure of the entire system, and allows you to define the properties of the system, characterizing the rate of reaching the system limit state. Weibull distribution gives the possibility to simulate processes of sudden failures (when distribution form parameter b is close to a unit, i.e. $b \approx 1$) and failures due to wearing ($b \approx 2.5$), and also when the reasons cause both these failure. Distribution also finely describes gradual failures caused by aging of the material, e.g. by corrosion. The advantage in application of the developed Weibull model of distribution is that the law is rather universal and for certain values of the parameter form and dynamics of change in the failure it takes the form: exponential (for $b = 1$, i.e, the failure rate is constant); normal (when $b = 3.3$); Rayleigh (for $b = 2$) the failure rate - a linear function); for $b > 1$ and $b < 1$ the failure rate increases and decreases, respectively. Weibull distribution allows to vary the distribution of parameters and apply it to a large number of cases of probability changes. As a logarithmic distribution, it describes satisfactorily the operating time to failure of various units of machines, bearing temperature sensors. In IUT it was defined, that the reliability of oil and gas equipment is also subject to the Weibull law. Thus, we assume that the predominant use of the law of the Weibull model in the development of safety model and in the description of the intensity of parameter changes of technical condition of the equipment and facilities of oil transport systems consisting of multiple elements with a variety of cause-and-effect relationships. Table 1.

Table 1. Distribution function of index of persistence.

Distribution function	Type of distribution function	Basic param eters	Function chart
Normal	$P(y) = F\left(\frac{y-m}{\sigma}\right) + 0{,}5$	*m, σ*	
Weibull	$P(y) = e^{-\left(\frac{y}{a}\right)^{b}}$	*A, B*	
Exponential	$P(y) = e^{-(\lambda y)}$	*λ*	
Gamma	$P(y) = \int_0^y \frac{\lambda^c}{G(c)} y^{c-1} e^{-\lambda y}$	*λ, c*	
Releigh	$P(y) = e^{-\frac{1}{2}\left(\frac{y}{\sigma}\right)^{2}}$	*σ*	

The type of distribution function is proposed to determine, applying the criteria of acceptance of preliminary engineering assessment of technological features of systems.

Analysis of experience in application of methods of probability theory in assessing the reliability of oil transportation equipment and facilities shows that possible criteria of consent to assess the types of distributions are criteria of K. Pearson, V. Romanovsky, Mises, etc.

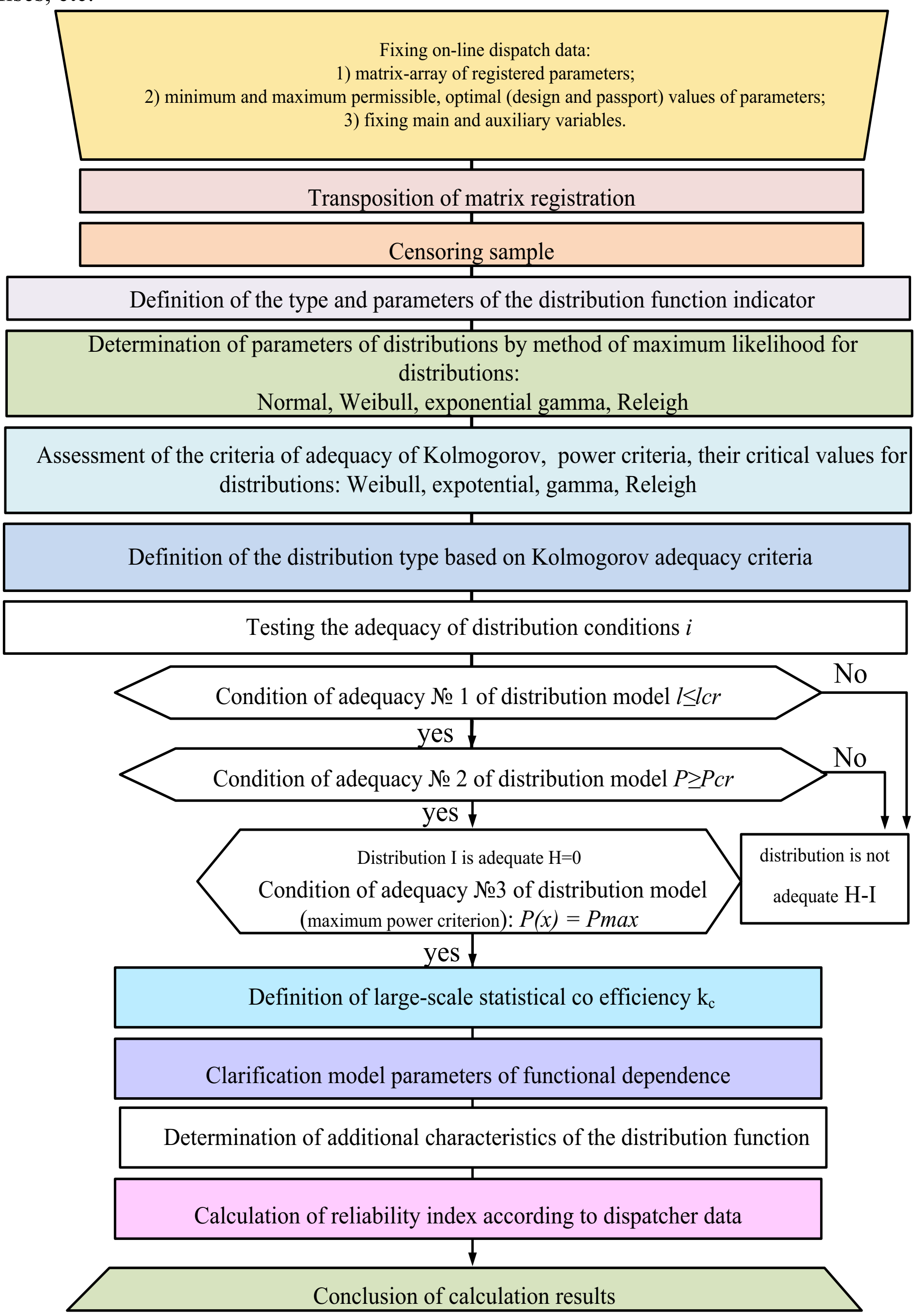


Fig. 1. Algorithm of program realization of the model of analysis of technological parameters.

It should be noted that an important stage in the developed technique is the necessity to check the quality of coordination of the empirical distribution with a hypothetical.

However, the evaluation of adequacy of type of distribution of the analyzed parameters we can carry out using the most appropriate criterion of A. Kolmogorov, as the most versatile, accurate and adequate to check the distributions of continuous processes of complex multi-element technical systems.

For comfort of application of mathematical apparatus the distribution function should be determined for deviation of technological parameter from optimal according to the model. If the deviation from the optimum parameter is not in the middle of the interval $y_i \in \left(y_{\min Cr}; \mathrm{y}_{\max\mathrm{cCa}}\right)$, the deviation will be determined using scaling methods.

Thus, in accordance with the method by A. Kolmogorov as a measure of discrepancy between theoretical and experimental distributions, we'll use the maximum value of difference between empirical and theoretical functions.

Since the developed technique of an estimation of distribution parameters is specific depending on the type of distribution, we'll take as an example the algorithm for estimating the Weibull parameters using the maximum likelihood method: .

1. Probability density is determined (derivative of the probability distribution function), assuming that Weibull distribution is the three-parameter:

$$f(y,\alpha,\beta,\gamma) = \frac{\beta}{\alpha}(y-\gamma)^{\beta-1} e^{-\frac{(y-\gamma)\beta}{\alpha}},$$

$$y \geq \gamma, \gamma \geq 0, \beta > 0, \alpha > 0, \tag{1}$$

where α, β, γ - scale parameter, forms, position respectively.

2. Position parameter y is different from zero if it is known that for real parameter values of y value argument does not specify the function value.

Position parameter in the analysis of the reliability of technical systems is determined to be zero, if Weibull distribution is two-parameter:

$$f(y,\alpha,\beta) = \frac{\beta}{\alpha}(y)^{\beta-1} e^{-\frac{y^{\beta}}{\alpha}} \tag{2}$$

3. Maximum likelihood estimations of the parameters α, β are obtained using the equations:

$$n\alpha - \sum_{i=1}^{n} y_i^{\beta} = 0 \tag{3}$$

$$\frac{n}{\beta} + \sum_{i=1}^{n} \ln yi - \frac{1}{\alpha} \sum_{i=1}^{n} y_i^{\beta} \ln y_i = 0 \tag{4}$$

$$\bar{y} = \alpha^{\frac{1}{\beta}} G\left(1 + \frac{1}{\beta}\right) \tag{5}$$

4. There is the first approximation of the parameter according to the formulas (7) and (9) using the method of successive approximations. 5. After the evaluation β α is determined:

$$\alpha = \frac{\sum_{i=1}^{r} y_i^{\beta} + (n-r)y_r^{\beta}}{r} \tag{6}$$

$$r = \frac{N_{df}}{2}, \tag{7}$$

where N_{df} – the number of degrees of freedom .

6. Distribution parameters are elaborated in real time as data become available and increase of volume of statistics.

7. Probability is determined (reliability index of the parameter) in Weibull distribution:

$$P(y) = e^{-\frac{y^{\beta}}{\alpha}} \tag{8}$$

or $$P(y) = e^{-\left(\frac{y}{a}\right)^{b}} \text{ when } a = \frac{\alpha}{\beta}; b = \beta \tag{9}$$

8. An evaluation of the correctness of the analysis of reliability is carried out for the following quantities (it should be noted that similar functios (12) and (13) and accepted designations are used in modern programming environments such as Matlab):

- intensity of parameter changes or failures:

$$\lambda(y) = \frac{\beta}{\alpha} y^{\beta-1}; \tag{10}$$

-mathematical expectation:

$$\mu_y = \alpha^{1/\beta} G\left(1 + \frac{1}{\beta}\right); \tag{11}$$

-dispersion:

$$\sigma^2{}_y = \alpha^{2/\beta}\left[G\left(1+\frac{2}{\beta}\right) - \left\{G\left(1+\frac{1}{\beta}\right)\right\}^2\right]; \tag{12}$$

-coefficient of variation:

$$k_v = \sqrt{\frac{G\left(1+\frac{2}{\beta}\right)}{G\left(1+\frac{1}{\beta}\right)^2} - 1} = \frac{\sigma_y}{\mu_y} \tag{13}$$

9. The values of the coefficients of variation kv, are checked , which should be within the following limits:

normal law $k_v \leq 0.4$;
the law of the Weibull distribution, $k_v = 0.35 \ldots 0.8$;
the exponential law, $k_v > 0.8$.

10. The conclusion is made (eg, based on the results of experimental data): analysis of changes in the y values for the object revealed that the change in absolute values of the operational parameters is subject to the normal law and deviations of these parameters - to Weibull distribution).

Since the definition of the form of the distribution function and assessment of the adequacy of its parameters are based on probabilistic-statistical method of Kolmogorov, in Matlab environment it is possible to implement the methods to use functions KSTEST of Kolmogorov-Smirnov (non-contradiction of general combination to law, the law with fixed parameters). The following conditions are checked as a result of calculation:

$$P \geq P_{cr} \quad \text{and} \quad l \leq l_{cr} \tag{14}$$

When H=0 probabilistic-statistical model is adequate. Among the alternative hypotheses about the form of distribution law the hypothesis with the greatest test of significance P is accepted (power of test).

3 Conclusion

Thus, the developed mathematical model and algorithms enable us to obtain a set of indicators that adequately characterize system reliability for time-varying parameters of the technical condition of oil and gas equipment.

The obtained mathematical models enable operating organizations, Federal services of supervision, independent expert organizations to assess and predict the development of reliability on a register block control data, in real time, taking into account the dynamics of the operating conditions of the object.

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