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System of Controlling the Reliability of Hydraulic Machinery in Oil and Gas Facilities

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Abstract. Under current conditions of operating hazardous production facilities and the level of environmental regulations, a crucial issue is evaluation and control of technological machinery reliability in hydrocarbon transportation. The authors have developed methodologies and a complex of models and algorithms aimed at creating a support system for control decision-making. It is based on the concepts of the reliability theory and regulatory requirements on technological machinery operation. A mathematical complex has been developed for predicting technical state changes and reliability in order to improve the decision-making efficiency concerning the necessity of preventive maintenance. The example is fundamental statements on reliability evaluation using fluctuation analysis.

Introduction

Today, the Russian Federation is implementing a complex of government programs intended to provide a reliable and safe operation of pipeline systems. Modernisation of the technical regulation system in 2009-2014, stiffening of requirements on production facility safety and corporate responsibility raised the significance of advancements in the field of equipment reliability monitoring and planning of measures for accident and incident prevention. The trunk line system is an elaborate complex of engineering structures with a system of providing safety and environmental compatibility. Analysis of operation practices on trunk line transportation facilities has demonstrated that around 95 % of incidents occur due to equipment failures and damage.

1. Control system requirements

In existing economic and ecological situation, a highly important task is determining the optimal inter-repair period considering its actual technical condition of equipment.

Current regulating industry standards [1,2] oblige hazardous production companies to operate their facilities under control of monitoring systems with quite precisely specified requirements and functions. According to government standards, a modern reliability monitoring service must perform the following functions:

- develop recommendations on equipment operation to increase its inter-repair period;
- develop recommendations on time schedules of taking equipment down to repairs;
- collect data on equipment reliability and actual state based on repair and operation results;
- analyse data from diagnostic network server in order to control the work of services on maintenance and repair of technological equipment, diagnostic network maintenance, etc.

In conditions of toughening the requirements it is necessary to develop decision-making support systems based on equipment reliability monitoring. Decision-making support systems [1,2,3] include properties of diagnostic systems and must provide instructions for personnel to prevent hazardous state of the facility and bring it to its normal state.

Generally accepted standards on inter-repair periods have been established for equipment with a set operation resource and are still meant for stabilised operation periods (figure 1). In some cases, for low-cost components with simple wear-out reliability models it is rather effective. However, under modern operation conditions and the complexity of technological equipment with practices in prolonging statutory service life based on life ratio parameters, a most relevant problem is monitoring the reliability of hydraulic machinery with estimated parameters. Most reliability parameter evaluation models are meant for the normal operation period (t_n-t_{cr}), however, in conditions of technical control of the system, even in the simplest case, the equipment reliability model changes (figure 2). The interval length increases (t_n-t_{cr} *), i.e. the normal operation period, and the starting point of the wear-out period (point t_{cr} *) and the function of the failure rate variable curve are unknown and depend on time and a number of factors x_n:

$$\lambda_{i(t)}=F(x_1,x_2...x_n;\ t) \qquad (1)$$

Determining by methods of mathematical analysis with the help of the expert system the predicted formula and value of function $\lambda_{i(t)}=F(x_1,x_2...x_n;\ t)$, with probability Pi and the reliability parameter value, we can legitimately evaluate the machine reliability in the period (t_{cr}-t_{cr}*) and make decisions on the possibility of its operation or control decision-making upon reaching maximum admissible rate parameter λ_{adm}.

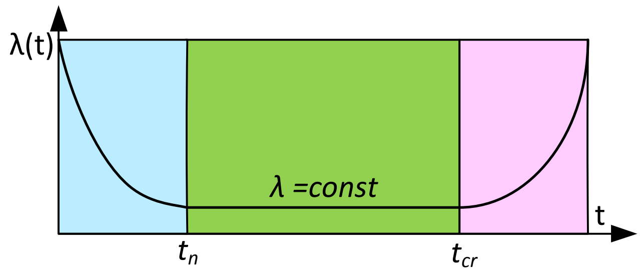

Figure 1. A typical curve of failure rate.

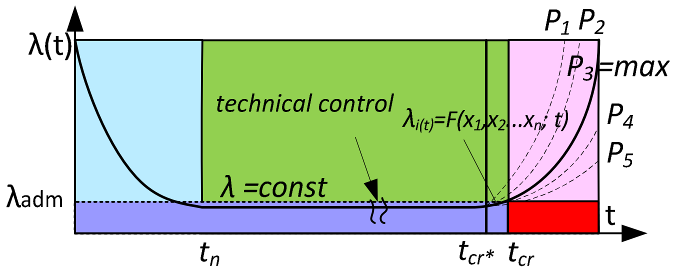

Figure 2. A failure rate curve of a complex machine in result of technical control.

The designed expert system is based on the multivariable predictive control (MPC) technology and the technology of real-time optimisation according to actual operation data. Such systems are designed individually taking into account the features and structure of the production facility using the methodological evaluation complex and the reliability parameters predicting complex. They enable transitioning from a set system of scheduled preventive repair and maintenance by operating time to servicing by actual and predicted state.

So, the primary goal of operational services is maintaining serviceable and fail-safe operation of the hydraulic machinery. The solution of this hard problem is based on strict observance of requirements of the specifications and technical documentation on the organisation of equipment maintenance and repair. These requirements, as a rule, come down to the annual time plan of scheduled preventive maintenance (SPM), according to which it is necessary to qualitatively and in a timely manner perform planned repairs on pumping power units. However, this situation does not eliminate premature equipment breakdown.

In a number of cases, forecasting system malfunction is possible when using the models of parametric failures that can be predicted by state parameters behaviour. Using mathematical methods determines the dependence of state parameters on other physical parameters («perturbations»), which accidental fluctuations are the primary cause of malfunctions later developing into failure.

2. Methods, results and discussion

The authors have developed innovative design procedures and mathematical models of reliability parameters [3-14] compatible with:

- the modern production system of maintenance;
- the system of recording operational supervisory data;
- the system of non-destructive control diagnosis in discrete measurement;
- the automated systems of technological process control.

The developed models of parameters of oil and gas facilities reliability provide the possibility for:

- forecasting the technical facilities parameters in real-time or over a fixed time span;
- the structural and factor system analysis for optimum service.

The methodology of determining reliability on the basis of studying the parameters characterising the technical state of the system, involves identifying the regularities of degradation processes leading to failures and finding analytical connection of these regularities with the reliability parameters. Depending on the character of the test parameter implementation various mathematical models are applied.

In Tyumen State Oil and Gas University a complex of mathematical models and algorithms for reliability prediction on parameter implementation has been developed.

The problem solution is based on the mathematical model of facility functioning as a dynamic system. A deterministic functioning model is taken as a basis. The model represents transformations of random input parameters ("perturbations") into target parameters of the dynamic system ("states"). The main forecasting stages are given in figure 3.

In a number of parametric reliability calculation problems it is impossible to neglect the state variables variation in time. The random process is identified by means of both theoretical and experimental research methods.

Studying the behaviour of parameters is conducted based on the sampled data and divided into three basic stages: 1) recording the parameter in a number of sections; 2) analysing each interval; 3) constructing a smoothed average, identifying the reference value and analysing the parameter trend.

In this case, the calculation method is based on the theory of random processes overshoot. The random process overshot $\zeta(t)$ over the Xcr level means the presence of such a continuous section within which $\zeta(t) \geq X_{кр}$, and before and after which $\zeta(t) < X_{кр}$.

A stream of overshoots is characterised by the operating time before the first overshoot (crossing), the operating time between overshoots, the duration or area of staying outside the set limits, etc. The parameters of the stream of overshoots are: mathematical expectation of the operating time before or between overshoots, rate of the first overshoots or overshoots in general, probability of an overshoot at a given operating time, mathematical expectation of the number of overshoots within the given interval, relative duration or area of staying outside the set limits, etc. The simplest and most frequently occurring are models in which failure is represented as the first crossing by each implementation of a random process $\zeta\ (t)$ with the critical level Xcr (figure 3).

Any of the basic technical parameters at the set modes and service conditions, as a rule, can be presented as a compound random process (2):

$$\zeta(t) = Q + \eta(t) + \chi(t), \tag{2}$$

where Q - the parameter reference value; $\eta(t)$ – the parameter trend; $\chi(t)$ – parameter fluctuations (harmonious changes of the kinematic or dynamic origin).

The parameter of the *i-th* system is presented in the form of a certain function ${}^{i}\zeta(t)$ with structure (3) matching (2):

$${}^{i}\zeta(t) = {}^{i}Q + {}^{i}\eta(t) + {}^{i}\chi(t), \tag{3}$$

where ${}^{i}Q$ - the parameter reference value in the *i*-th implementation; ${}^{i}\eta(t)$ – the parameter trend of the *i*-th implementation; ${}^{i}\chi(t)$ – parameter fluctuations of the *i*-th implementation (harmonious changes of the kinematic or dynamic origin).

For example, operation of gas compressor units (GCU) and pumps is characterised by a complex interaction of its components. Depending on the unit type (brand, model, drive, purpose), both a complex of measurements and a technique of the analysis of all parameters and their interconnections will be different.

Condition monitoring of gas compressor units can be carried out on the basis of key parameters defined during operation with a high precision, such as: effective power, fuel consumption per hour, rotational speed of rotors, temperature characteristics (for example, temperature of gases before the turbine, input and output values of gas temperature and pressure), lube oil pressure and temperature, gas composition, etc. Based on the dynamics of test parameters it is possible to carry out the analysis of malfunctions according to design plans and regulations. However, for preventive control of unit reliability, its structural or functional subsystem, forecasting of parameters applying the developed mathematical apparatus for the analysis of registration parameters is necessary.

In tests, mathematical analysis of observation results, as a rule, is based on the statistical analysis of each successive recorded implementation. The reference value and trend are then calculated on the basis of a smoothed average (4)

$${}^{(i)}\overline{\zeta}(t) = {}^{i}Q + {}^{(i)}\eta(t) \tag{4}$$

A smoothed average is the reference value and slow changes of the parameter on operating time t.

In case the process can be described as a deterministic periodic process, the periodic component is calculated as harmonious elements using the Fourier transformation and peak analysis (5), then:

$${}^{i}Q = {}^{i}z_k(t) = \sum_{v} \left[A_k \cdot \sin \omega t + B_k \cdot \cos \omega t \right] \tag{5}$$

where ${}^{i}z_k(t)$ - the deterministic periodic component of the process parameter; v - significant peaks of the Fourier transformation; A_k, B_k, ω, - harmonic function parameters; k - ζ(t)=xnumber of the observation interval.

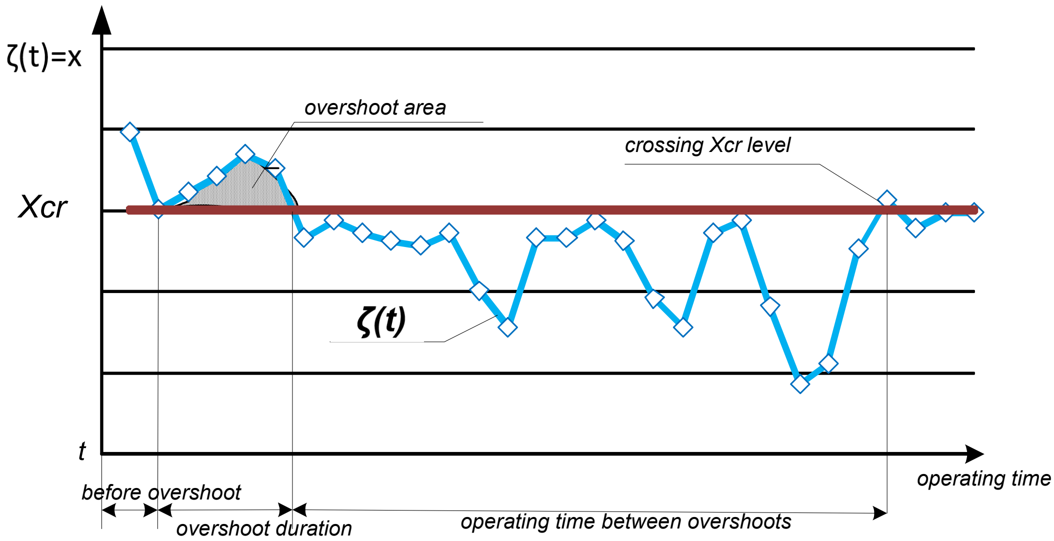

Figure 3. Random process overshoots above the admissible level (the X_{cr} level).

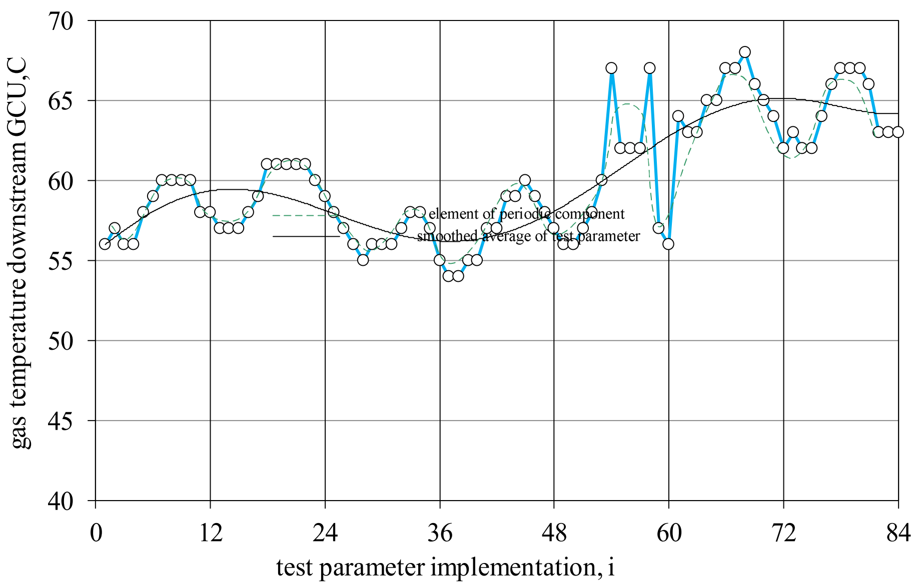

Figure 4. An example of test parameter implementation on the discrete model of recording GCU parameters.

Basing on mathematical analysis, the law of random parameter component distribution is determined. Unlike known models of reliability, the suggested technique and algorithms (figure 5) allows us to use the most adequate types of distributions from a complex of typical distributions both at a constant and variable failure rate.

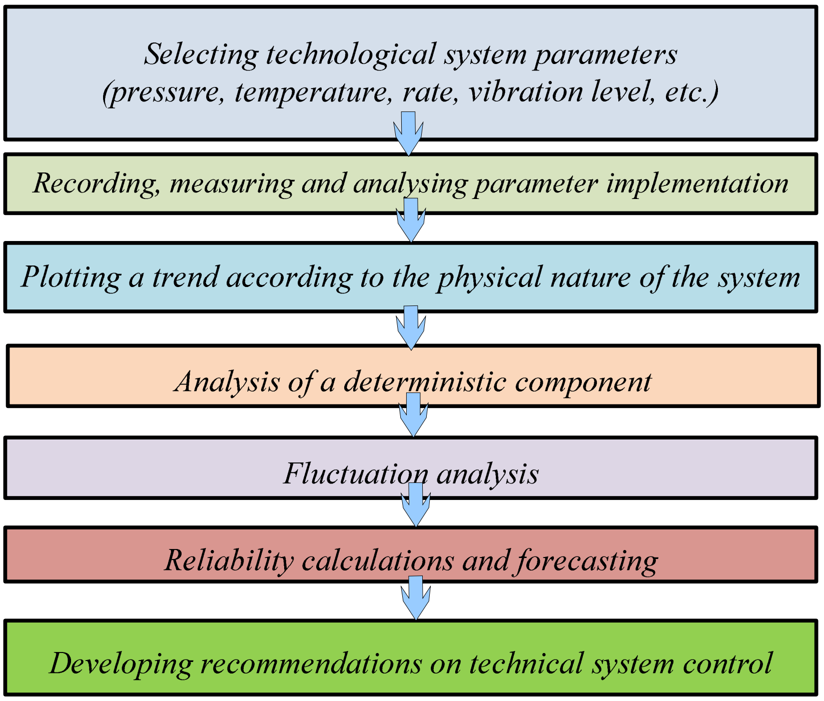

Figure 5. An algorithm of forecasting on the test parameter dynamics using fluctuation analysis.

Results can be gained both in the form of the expected parameter value and the probability of parameter staying within the admissible area. Calculation techniques are an extensive and elaborate mathematical complex, so calculations are done using relative computer software.

In practice, these methods can be used together with diagnostic software to improve the reliability and efficiency of equipment operation, as well as to prevent failures using the acquired information on system conditions.

Conducting repairs based on the actual technical state reduces the expenses for a part of the works performed during planned repairs, and maintenance in an optimum mode leads to fuel saving and prolonged inter-repair periods in particular.

3. Summary

Practical value of this work is seen in developing a complex of mathematical models and methods for the on-line reliability parameters monitoring system facilitating the transition from the "after-failure" service and maintenance system to "preventive" based on the predicted reliability parameters.

Therefore, solving the problem of predicting changes in the technical state of a complex system on the test parameter dynamics, it is possible to ensure safe operation by means of adjusting modes, as well as creating a system of early detection of negative changes. The proposed method of parameter processing and forecasting makes it possible to produce well-timed recommendations on the facility state in order to plan justified periods of taking the equipment down for repairs, the extent of control and material and labour supply.

References

[1] Condition monitoring and diagnostics of machines Hazardous equipment monitoring. Requirements for monitoring systems GOST R 53564 (2009-2010)

[2] Condition monitoring and diagnostics of machines Hazardous equipment monitoring. Organizational procedures GOST R 53563 (2009-2010)

[3] Yu D Zemenkov, V V Shalay, M Yu Zemenkova Immediate analyses and calculation of saturated steam pressure of gas condensates for transportation conditions Procedia Engineering **113** (2015) 254-258

[4] Yu D Zemenkov, V V Shalay, M Yu Zemenkova Expert systems of multivariable predictive control of oil and gas facilities reliability Procedia Engineering **113** (2015) 312-315

[5] Y N Antip'ev, A P Nevolin, Yu D Zemenkov Operation of intermediate pumping stations on transport of gas saturated oils 10 (1981) 46

[6] P Iljyashchenko D A Chinakhov Y M Gotovshchik MAW productivity development and reduction of its harmful effect on human organisms J Applied Mechanics and Materials **682** (2014) 122-126

[7] D V Valuev V I Danilov Reasons for negative formation of structures in carbon steel processing of pressure J. Proceedings 2012 7th International Forum on Strategic Technology IFOST 2012. 2 (2012) 151-154

[8] D P Iljyashchenko D A Chinakhov Y M Gotovshchik Investigating the influence of the power supply type upon the properties of the weld joints under manual arc welding J Advanced Materials Research 1040 (2014) 837-844

[9] R A Gizatulin D V Valuev A V Valueva A Serikbol I F Borovikov Optimizing technological parameters of the reduction processes in treating steels in a ladle furnace J IOP Conference Series: Materials Science and Engineering 91 (2015)

[10] Stepanov S., Cheremisin N., Sokolov S., Altunin A., Shabarov A. Computational method for relative permeability curves based on the bernoulli generalized porous media equations ECMOR 2012 - 13th European Conference on the Mathematics of Oil Recovery (2012)