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SYNTHESIS OF INTELLECTUAL SUBSYSTEMS OF DYNAMIC DIAGNOSIS OF THE CONDITION OF TURBINE UNITS THERMAL POWER

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Abstract. *Technique of creating a sub-line diagnostics status turbine unit thermal power plant based on an analysis of its diagnostic features. Rapid assessment of the technical state of turbine unit allows an early stage to detect the possibility of an emergency and to localize it. It involves the integration of the subsystems of the existing process control system (PCS), which will allow more efficient use of its information, hardware and software. Evaluation of the technical condition of the turbine unit thermal power plant is proposed to determine the use of modern intelligent technologies. The proposed method was used in the development of rapid diagnostic subsystems technical state of turbine of thermal power in Almaty.*

Keywords: technical diagnostics, intelligent technologies, expert systems, fuzzy systems, neural networks

SYNTEZA INTELIGENTNEGO PODSYSTEMU DYNAMICZNEJ DIAGNOSTYKI STANU TURBOGENERATORÓW ELEKTROWNI CIEPLNYCH

Streszczenie: *Zaproponowano metodykę opracowania podsystemu dynamicznej diagnostyki stanu turbogeneratora elektrowni cieplnej, która bazuje na analizie jego cech diagnostycznych. Dynamiczna ocena technicznego stanu turbogeneratora pozwala na wykrycie we wczesnym stadium awaryjnych sytuacji i jej lokalizacji. Proponuje się integrację tego podsystemu z istniejącym systemem automatycznego sterowania procesem technologicznym, co pozwoli bardziej efektywnie wykorzystać jego informacyjne, techniczne i programowe zabezpieczenia. Ocena technicznego stanu turbogeneratora elektrowni cieplnej proponuje się określić z wykorzystaniem współczesnych technologii inteligentnych. Zaproponowana metodyka była wykorzystana przy opracowaniu podsystemu diagnostyki dynamicznej stanu technicznego turbogeneratora w elektrowni cieplnej w Almaty.*

Słowa kluczowe: diagnostyka techniczna, inteligentne technologie, systemy eksperckie, systemy rozmyte, sieci neuronowe

Introduction

The rapid pace of development and implementation in all areas of modern engineering systems, continuous growth of their structural complexity and dimension, special conditions of use, and reliability requirements for running the equipment features define the relevance of reliability issues, the quality and safety of operation of technical facilities. Of great importance in the successful solution of these problems methods and means of control and diagnostics of technical systems and software.

When designing complex objects should incorporate technical control – in a timely manner to determine the actual state of the object (in good, valid, pre-emergency alarm), and, in the event of a failure to effectively detect and troubleshoot faults.

Engineering practices are increasingly faced with the problem of solving the problems of diagnostics of complex technical systems with a large number of possible defects that require rapid containment to prevent serious consequences of the accident. Solving these problems requires the development of mathematical models, methods and algorithms for the effective detection of defects that are applicable not only in a specific application domain, but having a common property for a large class of technical systems.

The problem of optimizing the diagnosis for the purpose of the strategy rapid containment and elimination of defects significantly escalates, given the requirements of reliability of hazardous production facilities. This task assumes paramount importance for the system, the quality of the operation of which significantly affects the environment, and the failure to detect defects can lead to irreversible catastrophic effects.

Optimization of management decisions, to ensure operational control and diagnostics of technical condition of structurally complex systems is urgent, requiring special attention to the problem.

The principal possibility of improving operation and maintenance of the boiler and turbine units to meet modern requirements of ecology and safety, based on the solution of theoretical and practical problems of reliability analysis and reliability of complex technical systems. Modern technology requires the creation of universal methods of accurate assessment of equipment performance, both currently and in some past and future periods of time. Therefore, the development of effective methods of control of technological parameters of the power plant during operation, detection of defects and faults at an early stage

of their occurrence, as well as the definition of a residual resource is very relevant assessment of the technical condition of potentially hazardous elements of the technical system is mainly based on the structural analysis of the reliability of its components, dynamic control methods (diagnostics vibration parameters and thermo gas dynamic characteristics), and analysis of contaminants. diagnosis success is largely due to the correctness of the choice of informative parameters for the construction of the principal diagnostic models of the object and pattern recognition and identification systems measuring systems. However, not yet resolved the question of recognition of difficult-fault on a quantitative and qualitative assessment of functional and vibration parameters. Therefore, considered in this paper questions informative defect identification criteria in the turbine unit is an actual scientific tasks. Of course, the decision of problems of diagnostics requires modern systems of automatic control and regulation of the boiler and turbine units, systems for collecting and processing information.

In the first stage of industrial development to ensure operational reliability and good technical condition of technological equipment (hereinafter – MOT) was carried out "to the full." In the second half of the last century, there was, and has been used successfully to date, a different direction – scheduled preventive maintenance. However, market conditions, it becomes apparent – it is necessary to move to a more progressive strategy for operational reliability TO – "in his actual condition." The transition to this strategy calls for the creation of rapid diagnostic system maintenance the state. Application of the assessment system in its actual condition improves efficiency by reducing the time, reduce production costs of repair downtime by reducing the cost of repairs and disaster recovery equipment.

The cost of creating an automated on-line diagnostics system will be reduced considerably, if it will be included in the current structure of the automated process control system (PCS) as its subsystems. In this case, the information will be used to ensure the current process control system, which significantly reduces the cost of its development and implementation. In this case the effect of the introduction of enhanced process control system will increase significantly, because in addition to the effects of rapid and optimal process control is achieved and the effect of rapid diagnostic TO. In addition, with the possible occurrence of the so-called expected synergies – when the effects of the process control system and subsystem operational diagnosis is much higher than their simple sum. This is the result of interference of process

control and diagnostics TO: on the one hand and optimum operational management process, a positive impact on the way and on the other – on-line diagnostics enables you to save the state at the appropriate level, thereby improving its handling. diagnostic functions enable the subsystem at an early stage to fix the beginning of the destructive processes in the MOT and locate them in time.

The solution of these tasks takes the utmost importance for the systems, the quality of the operation of which significantly affects the social and ecological conditions, and failure to detect defects can lead to irreversible catastrophic effects.

1. Relevance of performing diagnostics of turbine

In the CIS countries, the amount of equipment, has worked for more than 25 years was 50% or more [1, 5]. Therefore, in thermal power plants in almost all mills observed physical and technological aging equipment that poses the problem of diagnosis of its technical condition of one of the top priorities in the power sector.

An important element of the operation and maintenance of turbines is the continuous monitoring of the operating status. Detection of any defects and prevent them at an early stage of development, as well as timely the right decisions to eliminate defects before an emergency, subject to availability of the required amount of reliable information, provide high availability, reduce downtime, reduce the cost of repair, life extension turbines equipment [1, 3].

The most unreliable nodes and turbo systems are [1, 2]:

- 1) Hydraulic system – the number of failures of 9.7% (at the time to recover to 40% of the total time scheduled for major repairs).
- 2) The control system – 23%, recovery time – 18%.
- 3) Steam distribution – 13%, recovery time – 8.5%.
- 4) The turbine unit bearings – 16%, recovery time – 19.6%.
- 5) Lubrication system – 8.3%, recovery time – 5.2%.
- 6) Pipes and fittings – 11.4%, recovery time – 5.2%.
- 7) Other turbine components and spare parts – 10.4%, recovery time – 11.1%.

Not the best performance and turbines manufactured in Germany, USA, Switzerland, Japan [2, 4] working on the old parameters of the working medium.

Thus, the greatest damage is applied to turbine defects in the elements of a flowing part, when the time spent on the restoration of more than 60% of the total time for repair.

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2. Concept of the three-stage procedure of diagnostics of a turbine

Turbines (TA) as a diagnostic facilities have the following characteristics:

- TA complexity makes it impossible universal solutions, it causes difficulty in diagnosing algorithms and requires different approaches to solving specific problems.
- Insufficiently high controllability TA, measuring parameters necessary to find defects.
- The need to identify faults at an early stage of their to prevent failures.
- The nature and complexity of pluricausal failures occurring in the TA.

In this regard, the development and implementation of diagnostic methods are in areas that are most adapted to the design features of TA in operation. These areas are:

- Diagnostics of the change of dynamic processes parameters (vibroacoustic diagnostics, diagnostics of the parametric performance of the unit);

- Diagnostics of the change of physical and mechanical parameters of the diagnosis object (visual and optical diagnostics, etc.)

The level of diagnosis of technical condition of the machine close quantitative indicators, which include:

- Accuracy – compliance with the parameter obtained in the diagnosis, its actual value.
- Reliability – diagnostic minimum probability of errors.
- Performance.
- The cost of [2, 6, 7].

Having effective tools, as well as the calculation methods and diagnostic tools, allows, also, to operate machines for the actual technical condition that ensures a higher level of machine reliability and significantly reduces the costs associated with the scheduled preventive maintenance work, reducing the need for spare parts and repair Staff increases the quality of the repair.

To date, the operating conditions in one way or another use the following types of diagnostics: Parametric, on used oil analysis, optical, acoustic and other methods to survey units and parts TA [1, 3, 5, 6].

3. Identification of diagnostic signs of assessing the state of a turbine plant TPP equipment

For Energy is currently characterized by the intensification of the use of facilities and resources of the installed equipment. This can be achieved through intelligent diagnostic operational status of equipment and use regimes. The growth of the degree of responsibility of the decisions on the time display of equipment for repair has tightened the requirements for the quality of the identification of models which are based on information obtained in the diagnosis of the state of the TA. Their implementation in the conditions of the old forms of maintenance on the SPR system (preventative maintenance) was ineffective. There appears to be a lack of adequate diagnostic models and models of decision-making on the withdrawal of TA to repair or load reduction, due to the non-use of fuzzy information about the condition of the equipment, as well as increasing the total uncertainty, accumulated during the operation. [1, 5]

In order to implement the above-proposed three-stage procedure for creating diagnostic subsystem in the case of turbine we conducted a survey of operators, technicians and engineers of the turbine shop of Almaty CHP-2, which showed that the main variables that characterize the state of the turbine unit as a whole, are as follows:

- X1 – vibration of the thrust bearing,
- X2 – vibration support bearing,
- X3 – temperature babbitt thrust bearing,
- X4 – temperature babbitt thrust bearing,
- X5 – axial shift in the direction of the generator,
- X6 – axial shift towards the chair,
- X7 – the relative expansion of the high pressure rotor,
- X8 – the relative expansion of the low-pressure rotor,
- X9 – the hydrogen pressure in the generator housing,
- X10 – the temperature in the hydrogen generator housing,
- X11 – the oil temperature after the oil cooler,
- X12 – the pressure in the discharge chamber of high pressure cylinder,
- X13 – temperature steam,
- X14 – pressure steam,
- X15 – the fall of the vacuum in the condenser,
- X16 – metal temperature in a high pressure cylinder,
- X17 – metal temperature in the low pressure cylinder.

All of these variables are controlled appliances shop service of instrumentation and automation (I), which makes it possible to synthesize the automated system of operative diagnostic of technical state of turbine CHP.

In accordance with our proposed method [2, 5], you must create a planning matrix of full factorial experiment (PPE) for the

synthesis of intelligent diagnostic and predictive models. However, in this case, you will need to spend a huge amount of "thought" experiments, for example, for 3-level assessment of the number of data points will be $N = 317$, which is absolutely impossible to implement.

In this connection, it is necessary to decompose the task of forming the matrix PPE planning. To this end, we offer to evaluate the effect of diagnostic features (DP): $X1 - X17$ on the condition of not just the turbine unit as a whole and its individual main parts that will reduce the impact of the "curse of dimensionality" on the formation of PPE matrix.

Given the fact that the steam turbine PT-80 is a single-shaft two-cylinder machine designed for direct drive generator, we propose to consider a set of turbine following main elements arranged on the same shaft: the support bearing (OP); cylinder and high-pressure rotor (CVP); cylinder and low pressure rotor (LPC); alternator (ATG); thrust bearing (UP). In addition, given the particular dangers we asked to see the hydrogen supply system (IPS) in the generator housing as a separate component that is not associated with the other one shaft (see Fig. 1).

Figure 1 shows that the technical condition of the bearing vibration influence, babbitt temperature and oil temperature, and the evaluation of the technical condition of the bearing 10 (Y_{op} and Y_{up}), in turn, are diagnostic features for the evaluation of the technical state of HPC, LPC and ATG. It is necessary to consider the fact that these elements are equally affected by the state of the turbine as a support and thrust bearings. In this connection, it is proposed to take into account assessment of the technical state of only one of the 10 bearings having a worst-case assessment of the value (denoted by the value of this evaluation through Y_n).

Accounting for a general assessment of the technical condition of the bearings (Y_n) will reduce the number of APs per unit for each of the three basic elements: HPC, LPC and ATG.

Evaluation of technical state of the most dangerous hydrogen supply system (Y_{spv}) depends on hydrogen pressure and temperature in the generator housing. At the same time, together with other Y_{spv} DP ($X_{5,6}$, Y_n and X_{11}) can serve as baseline data for the evaluation of the technical condition of the generator as a whole.

Thus, the axial shift towards the generator (X_5) and the axial shift towards the chair (X_6) are mutually exclusive factors, i.e. shift can be carried out either in one or the other side, so we combined these two factors alone – $X_{5,6}$, which reduced the number of APs per unit for each of the three basic elements: HPC, LPC and ATG.

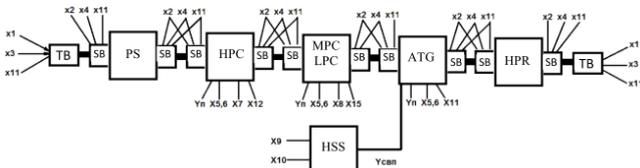


Fig. 1. Elements of the turbine unit and PD effect on their technical condition

In addition, the variables X_{16} (metal temperature in the high pressure cylinder) and X_{17} (metal temperature in the low-pressure cylinder) are DP to assess the technical condition of HPC and LPC only in the process of their preparation for launch during heating. During the normal operation of the turbine unit are not controlled by a person, so we have excluded from the number of APs, thus further reducing the dimension of the problem to be solved by us.

Variables X_{13} (steam temperature) and X_{14} (steam pressure) are purely technological, depending on the physical condition of steam coming from the boiler plant. According to these variables is not possible to evaluate the technical condition of the HPC or LPC, so we have also excluded from the DP.

4. Synthesis and a research on adequacy of models of diagnostics of an assessment of a condition of TsVD

The basis of the proposed method of diagnosing the development of algorithms constitute the matrix PPE scheduling instead of the traditional rules of productions. Consider the method of forming the matrix PPE planning on the example of diagnosing the problem, "the loss of vacuum in the condenser".

Deterioration of the vacuum is quite a usual situation for operators, but has a great harm to the entire turbine generator, since there is risk of damage to the soma of the turbogenerator expensive – its rotor. The vacuum in the condenser is regulated by a circulating water temperature, flow and level of water circulation in the condenser.

The required level of water circulation and the parameters are known and are controlled by the process control system. However, if these parameters have not reached the desired value, it indicates the occurrence of pre-crash situation, which was the cause of one or more faults and breakdowns.

That is to say that if the vacuum change in the capacitor to a certain extent offset by a control action (a change of circulation water parameters, changes in the level in the condenser by increasing or decreasing the flow of condensation pump), the technical condition of the turbine unit is normal, and it is within the scope of control system (DCS).

At the same time, even if the level in the condenser has not gone beyond the acceptable limits, but not "subordinate" management system, which gives a command to increase or decrease it, it says that the situation is close to the emergency.

That is, you must go into the sphere of influence of the subsystem diagnostics to determine the cause, identify the problem and take steps to localize damage at the level of the "auxiliary" equipment, in order not to spread the state of the fault to another, usually more important "basic" equipment of turbine unit which is in contrast from "auxiliary" reserve equipment has.

5. Assessment of sensitivity of neuroindistinct model

Formation of the planning matrix PPE is the most time consuming and most important operation in the synthesis of intelligent diagnostic models.

Consider the assessment of the state of the simulation results of CVP (Y) for different values of the input variables: X_1 , X_2 , X_3 and X_4 .

Figure 2 shows the results of simulations to evaluate the technical condition of CVP (Y) depending on changes in the general state of the thrust and journal bearing (X_1) for different values of the discharge pressure CVD chamber (X_4), equal to the maximum ($X_4 = 1,0$), average ($X_4 = 0,5$) and minimum ($X_4 = 0$) values. Modeling was performed at nominal values of the axial offset in a forward or stromtium generator chair ($X_2 = 0$) the relative expansion of high-pressure rotor ($X_3 = 0$).

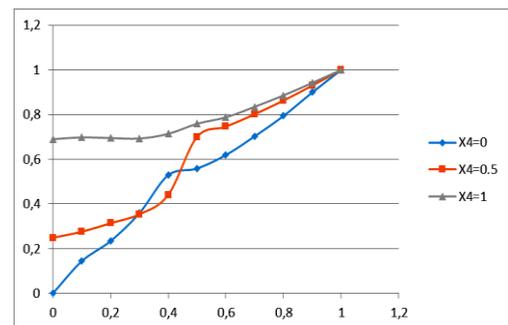


Fig. 2. The results of modeling to assess the technical condition of CVP depending on the change in the discharge pressure chamber at 0 and $X_2 = X_3 = 0.5$

Figure 2 shows that the maximum value ($Y = 1$), the technical condition of the characteristics of HPC is at the maximum values of the general state of the thrust bearing ($X1 = 1$) for all values of pressure in the discharge chamber CVP ($X4 = 0, 0.5, 1.0$). This is understandable – because the overall thrust bearing equal to ($X1 = 1$) is unacceptable and will inevitably entail stopping the turbine unit, according to the instruction manual [5]. At normal pressures in the discharge chamber CVP ($X4 = 0$) and in normal conditions the thrust bearing ($X1 = 0.0$) the general technical condition of the best CVP ($Y = 0.0$), and for the general deterioration of the thrust bearing to the technical condition ($X1 = 0.5$) general information technical condition CVP is satisfactory ($Y = 0.559$)

Figure 2 is clearly seen that the maximum in the discharge chamber pressures (the $X4 = 1$), and with nominal values of the technical condition of the thrust bearing of ($X1 = 0.5$), the overall technical condition of the CVP has a distinct freelance mode ($Y = 0.69$), which is characterized by poor state of the discharge CVD chamber, it is necessary to reduce the pressure in the discharge CVD chamber by discharge that is, reducing the supply to the turbine steam in order to prevent further destruction of the discharge chamber. And with the overall assessment of the technical condition of the thrust bearing equal to ($X1 = 0.5$) overall technical condition of the CVP attain to the level ($Y = 0.759$) that is unacceptable for long work turbine unit under these conditions.

From the above it can be concluded that the values of the pressure, i.e., the technical condition of the pressure chamber CVP ($X4$) is not critical, since you can always unload the turbine and thus reduce this figure. The value of the total index of the thrust bearing technical condition is critical for the general state of the turbine unit, due to the impossibility of reducing this indicator during the operation of the turbine.

Thus, taking into account reductions in diagnostic features, evaluation of each of the main elements of the turbine unit (TA) can be assessed only on the four DP, the most number of "mental" experiments for each part of the TA (HPC, LPC and GTP) will be $N = 34 = 81$, which is quite simple to implement.

Conclusion

Based on the analysis of literature and previous work of the authors can draw the following conclusions:

- 1) It is shown that the availability of effective tools, as well as the calculation methods and diagnostic tools, allows to operate the units for the actual technical condition that ensures a higher level of machine reliability and significantly reduces the costs associated with the scheduled preventive maintenance work, reducing the need for spare parts and maintenance staff, increases the quality of the repair.
- 2) The analysis of modern diagnostic methods showed that they require rather complex instruments and procedures for measuring and analyzing diagnostic signs with the need to develop complex mathematical descriptions of diagnostic facilities. In addition, almost all of the above methods are not suitable for the synthesis of the automated line diagnostics systems as part of the existing process control system.
- 3) Be based on intelligent technologies subsystem operative diagnostics as part of the existing process control system allow the use in its algorithms in one way or another the most effective methods of diagnosis: vibration diagnostics, parametric diagnostics and, if necessary, and the method of phase trajectories.
- 4) The concept of the three-stage turbine unit diagnostic procedure that considered proposed instead the creation of mathematical models of diagnosis and failure models of objects immediately begin to develop an algorithm of diagnosis using advanced intelligent technologies.
- 5) Diagnosis functions allow subsystem at an early stage to fix the beginning of the destructive processes in the TA.
- 6) The main diagnostic signs of assessing the state of turbine equipment.

- 7) Identified diagnostic signs permit in accordance with our concept, to start forming the matrix PPE planning.
- 8) Were synthesized and studied intelligent diagnostic model of technical condition of the turbine unit. It was found that the best model is the model built using neural algorithms.
- 9) Conducted simulations neural algorithms and their performance and compliance with the laws of the physical functioning of the CVP.

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