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OPTIMIZATION MODEL OF VIBRODIAGNOSTIC MAINTENANCE OF TURBOGENERATORS

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Abstract:
In optimizing the vibrodiagnostics of thermal power plants, a mathematical model was developed and used to increase the power plants' safety and operational characteristics. The choice of diagnostic condition parameters of the components was made based on optimization characteristics that affect the accuracy of the solution and operational readiness of the thermal power plant. The research aimed to develop a universal model by analyzing more optimized vibrodiagnostics of the turbogenerator, which achieves high operational reliability, high safety, an extension of service life, an extension of working life, a reduction of overhaul time, etc. The application of the model represents the concept of optimization with the checking of condition parameters, which is applied to turbogenerator assemblies that have a continuous change of condition parameters as a function of the monitoring time, for which the functional dependence between the intensity of the parameter change and the operating time can be determined.

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1. INTRODUCTION

Turbogenerators represent a crucial part of equipment in thermal power plants [1, 2]. The main criteria for the turbogenerator operation are high reliability, many starts, and flexible work [3]. Today, turbogenerators have increasing requirements for operational safety [4, 5]. This represents the basis for planning and implementing quality and necessary maintenance technology procedures practically. In order to maintain an appropriate level of safety in the operation of the turbogenerator, it is necessary to pay more attention to their maintenance and organization of exploitation [6]. Maintaining these technical systems aims to ensure continuous operation as long as possible and reach the maximum working life [7, 8].

The leading causes of low turbogenerator reliability are the appearance of a short circuit [9, 10], rotor imbalance [11], wrong assembly (weak connections) [12], deformed shafts [13], damaged bearings [14, 15], and so on. These factors affect the occurrence of vibrations and failures [16]. Vibration analysis is one of the techniques used in maintenance and is based on conditions, to monitor and analyze specific machines and equipment within technical systems [17-20]. Vibrodiagnostics is a support tool for ensuring the necessary reliability with the lowest possible cost of production, exploitation, and preventive maintenance [21]. Also, it implies knowledge of theory and models of process organization, diagnosis of turbogenerator components, principles of functioning, and use of diagnostic tools [22].

Technical diagnostics is a modern technology of preventive maintenance that belongs to the relatively new method, which includes program contents that are qualitatively connected by the analyzed influence of the phenomenon of reliability, mobility, and technology of preventive

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maintenance of turbogenerators [23]. Maintenance planning itself depends on the criticality of the equipment [24].

The development of the optimization model efficiency and vibrodiagnostic procedures is the introduction of appropriate parameters and methods to predict and prevent failures where all maintenance activities are associated with their operational risk. The optimization of the maintenance process has resulted in the extension of the work life of turbogenerator assemblies.

Model selection research represents the connection between the periodicity of checking parameters of the conditions “in operation” and “failure” of the main components of the turbogenerator. By analyzing parameters, it is possible to develop a model for determining the optimal period of operation of components to check their condition so that failure does not occur. The optimization procedure of vibrodiagnostics represents all activities carried out by introducing parameters and methods to evaluate the current technical condition of turbogenerator components to plan preventive maintenance activities. Optimization of vibrodiagnostic procedures is a problem with an ambiguous solution. Multi-criteria optimization of vibrodiagnostics is a complex process of finding solutions. It takes place in several stages, at several levels of decision-making, depending on whether and when additional information is known about the condition of the components in the work process.

Mathematically speaking, the problem of optimization of vibrodiagnostics is reduced to determining the extremum of the criterion function for monitoring the operation of turbogenerator components. For this purpose, various models were developed within the framework of the theory of production work, optimization of vibrodiagnostics, and mathematical programming [25]. Models are developed only for certain types of problems, and no algorithm is most suitable for all optimization problems [26].

2. MATERIAL AND METHODS

The paper analyzes the technical condition of the Turbogenerator TVF-100-2 in the thermal power plant Kostolac, “TEKO-A.” The diagnostic program included absolute and relative shaft vibrations. Absolute vibrations were measured at all aggregates, and relative vibrations were measured selectively. Vibration measurements were carried out using a vibration sensor manufactured by “Brüel & Kjaer.” The tests were carried out with the main goal of obtaining an optimal solution based on the recorded vibration data of the turbogenerator, which will provide broader information about the operational condition. Furthermore, the temperature was measured to diagnose the condition and damage of the bearings. The paper used MATLAB software for the mathematical modeling.

The technical diagnostics during work at the selected measuring points of the analyzed turbogenerator assemblies is based on determining the absolute and relative vibration of the shaft bearing. Data on the availability of their work in a specific time interval were used to determine the reliability of the components of the analyzed turbogenerator assemblies.

The multi-criteria planning of turbogenerator component assemblies involves making decisions with a very complex structure. Its preference structure is sometimes based on multiple criteria and models that help solve multic-riteria optimization problems. The way of participation and decision-making depends on the way of including the preference structure in the optimization procedure, and according to this, we can distinguish three approaches:

- The first approach uses a multi-attribute reliability function of components containing specific criteria and a preference structure in the form of a mathematical reliability function.
- The second approach is a two-step optimization procedure.
- The third approach is an iterative optimization procedure.

During all mode investigations, the vibration of the turbine, generator bearings, and the oscillations of the accessible parts of the shafts at the exit from the bearings were measured. The amplitude, frequency, and phase of bearings are measured in vertical and transverse positions.

Determining its condition is one of the most complex tasks in using turbogenerator assemblies. The existing condition (for each component of the thermal power plant, i.e., for each condition parameter separately) determines the working ability or proper functioning of the turbogenerator components. Taking into account all the necessary parameters, a universal optimal model of the analyzed assemblies has been created, representing the universal equation of the transfer function of the optimal operation (dependency of frequency security in the function of the production operation of the components and assemblies).

The functional dependence of the models and the time intervals of the components' operation until failure represent a specific safety of the functioning of the turbogenerator assemblies, namely the optimal mode of operation with the best reliability - optimal operation with permissible risk. Maintenance concepts can be created based on the universal safety model of the operation of the analyzed components and assemblies. In many ways, they contribute to better productivity of the analyzed turbogenerators.

In the research, solving the optimization of the vibrodiagnostic procedures of the turbogenerator components was carried out by applying the condition parameters of the components, forming a block diagram and a universal mathematical model. The basis of the mathematical model is represented by the cases of optimality based on meeting the technical and economic requirements of the turbogenerator and essentially represents an original approach to obtaining the most favorable optimization model of the turbogenerator vibrodiagnostics.

The presented mathematical model optimizes specific diagnostic parameters based on which the energy equivalent is determined. Based on the mathematical optimization model, an algorithm was developed that included the appropriate characteristics of the components of the turbogenerator. For the final evaluation of the operation of the turbogenerator assemblies, it was necessary to determine the appropriate standard statistical distribution of reliability. It is determined based on the transfer functions of the reliability of the components without and with the participation of preventive maintenance.

Fig. 1 shows the arrangement of measuring points on the tested turbogenerator TVF-100-2. Where: N_1- N_8 - sliding bearings, S_1- S_3 - coupling, LPT - low-pressure turbine and HPT - high-pressure turbine.

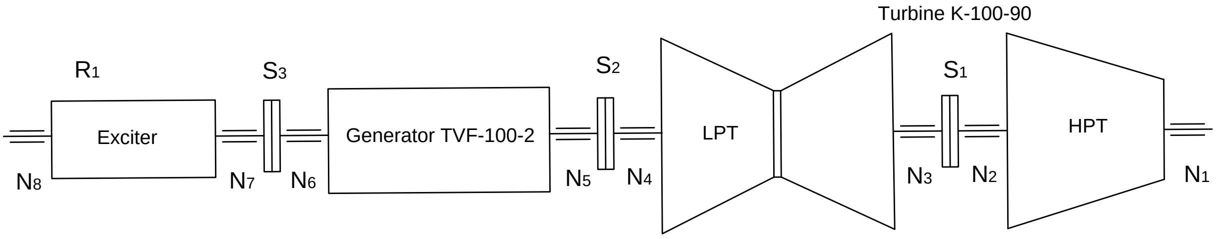

Fig. 1. Arrangement of measuring points on the tested Turbogenerator TVF-100-2

The number of failures was analyzed due to the increased level of mechanical vibrations, temperature changes, and bearing wear on the constituent components of the analyzed turbogenerator assemblies (Fig. 1). In the observed time of exploitation, the first failures occurred after ~40000 hours of work on the components on which the condition parameter control of the components was not applied and ~46400 hours of work on the component components on which the condition parameter control was applied.

3. RESULTS AND DISCUSSION

3.1. Development of an Optimization Model for Vibrodiagnostic Maintenance of Turbocompressors

In this chapter, a developed mathematical model is presented, which determines the connection between the periodicity of checking the parameter condition of the components of the assemblies and the signaling tolerance of the parameter condition of the components while ensuring the default condition of the components. This model establishes direct relationships between the reliability and legality of the condition parameter change of the observed components and has the immediate task of determining the output characteristics of the model: the time of the "first" condition check, the permitted value of the parameter condition and the signaling tolerance of the parameter condition within the limits of which it is necessary to carry out preventive maintenance procedures, to prevent the failure of components. The universal model of the program package automatically solved the process of monitoring the parameters of the component's condition and provided output characteristics that represent the basis for optimal monitoring of procedures in the processes of changing the condition of components, decision-making, and implementation of preventive maintenance procedures.

Conducted spectral analyses of random functions are determined based on basic statistical diagnostic parameters that describe the character of random functions, and they are of crucial importance for the analysis of the security model of the analyzed assemblies. The primary statistical diagnostic parameters used to analyze the condition value of the turbogenerator represent the arithmetic medium value p_A (the arithmetic medium dependence of the oscillation amplitude) at the measuring point as a function of the exploitation operation of the assemblies.

Arithmetical medium value dependence of oscillation amplitude - p_A random function $A_i(t)$ was calculated according to the following expression [27]:

$$A_{i,n} = p_A = \lim_{n\to\infty} \frac{1}{N} \sum_{i=1}^{n} A_i\,(t), \quad (1)$$

where:

i - number of measurement points,

n - turbogenerator component designation number,

N - number of equal time-subintervals (t_i) duration of random functions,

$A_i(t)$ - values of amplitudes of random functions in the observed duration (t_i) at selected measuring points.

The frequency amplitude values depend on the function $f = f(A_i)$ and the time duration (t_i), for the analysis of random functions and they were adopted based on a sufficiently large time interval, which was then divided into an equal number of intervals $\Delta t = t/N$.

During the conducted analyses, the amplitude and frequency values at the selected measurement points were measured for 10 minutes, and for each measurement, 2 minutes. This applies to records of the amplitude dependence on the duration of the measurement. The measurements were carried out at exactly predicted intervals during the analysis time of their operation from 40000 to 60000 hours.

The explicit dependence of the determination of the medium amplitude values by spectral analysis of random functions for the measurements carried out in a precisely defined exploitation work and at a precisely determined measurement location was calculated as follows [27]:

$$A_{i,n} = p_A = \lim_{n\to\infty} \frac{1}{3}[A_1(t) + A_2(t) + A_3(t)], \quad (2)$$

where $[A_1(t), A_2(t), A_3(t)]$ - amplitude values at the chosen measuring point of the assembly, for three repeated measurements and more accurate measurement results. This repetition of measurements aims to determine more precise values of the oscillation amplitudes to determine the values of the medium amplitude. It is relevant as a quantitative analysis of the optimal model of the safety components assemblies with their arithmetic medium value.

Tables 1. and 2. present the optimal mode of operation with the best reliability and permissible risk, i.e. the calculated medium values of the amplitudes $A_k(t)$ depending on the operating time (t) of the assembly components, presented at precisely defined measuring points for three consecutive measurements for each interval of the specified operating time of the components $t_i(h)$.

Table 1. Medium values of amplitudes for measurement locations and durations without application of parameter control of the components

Observed area	Allowed risk			Risk		Overhaul
t(h)	44000	48480	56160	44800	54720	>60000
A₁(t)	8.0112	7.8888	7.9	8.1888	8.1888	8.7664
A₂(t)	7.956	7.928	7.9248	7.9912	8.1584	8.5912
A₃(t)	8.5632	8.5632	8.3952	8.3312	8.3296	9.1296

Table 2. Medium values of amplitudes for measurement locations and durations with the application of parameter control of the components

Observed area	Allowed risk			Risk		Overhaul
t(h)	44000	48480	56160	44800	54720	>60000
A₁(t)	7.5696	7.6656	7.6928	7.8736	7.9296	8.5184
A₂(t)	7.4992	7.5952	7.6688	7.768	7.888	8.7168
A₃(t)	7.8512	8.0208	8.0576	8.0112	8.0288	8.7168

Since the reliability of the components of the analyzed assemblies directly depends on the amplitude values at the analyzed measuring points, it was necessary to perform a correlation of their mutuality. As the reliability of the analyzed assemblies was determined based on the selected statistical distribution, it was necessary to correlate these parameters and determine their dependence on correlation.

The functional dependence between the double higher amplitudes $2A$ *(f_0)* measured in (μm) and the generator power P_A in (MW) can be mathematically presented using equitation [27]:

$$2A(f_0) = f(P_A). \quad (3)$$

The adequate dependence is an approximation using linear regression or a polynomial of the 5th degree for measurement at measuring points 1 and 3 and a 4th-degree polynomial for measurement at places 2 and 3. Due to the generalizations of this solution, the best dependence is chosen in the form of a polynomial of the 4th degree and represents an optimization model.

The analysis included a polynomial of the 4th degree with real coefficients (a_1, a_2, a_3, a_4), and if we start from the general form of representation of a real polynomial of the n-th degree in the record, it follows:

$$f(x) = a_n x^n + a_{n-1} x^{n-1} + \ldots + a_1 x + a_0, \quad (4)$$

where:

a_{0-n} - coefficient of the real polynomial,

x^n - parameters of conditions components.

That's it $a_i \in J$, *i* = 0,1,2,3,......n, and $n \in N$.

The value of the analytic 4-th degree polynomial with n-th degree polynomial can be expressed as:

$$(Q - J)(t) = +a_4 A^4 + a_3 A^3 + a_2 A^2 + a_1 A + a_0, \quad (5)$$

where:

$(Q - J)(t)$ - a polynomial with real coefficients that gives the dependence of reliability as a function of the value of the components' operation,

A_i^n - amplitude values of measurement points,

a_i - real coefficient of condition parameters of the components.

To determine their real parameters, a system of equations will be set in a general form that includes the values of the coordinates of the points that determine this dependence [28]:

$$\begin{aligned} a_4 A_1^4 + a_3 A_1^3 + a_2 A_1^2 + a_1 A_1 + a_0 &= N^1 \\ a_4 A_2^4 + a_3 A_2^3 + a_2 A_2^2 + a_1 A_2 + a_0 &= N^2 \\ a_4 A_3^4 + a_3 A_3^3 + a_2 A_3^2 + a_1 A_3 + a_0 &= N^3 \\ a_4 A_4^4 + a_3 A_4^3 + a_2 A_4^2 + a_1 A_4 + a_0 &= N^4 \\ a_4 A_5^4 + a_3 A_5^3 + a_2 A_5^2 + a_1 A_5 + a_0 &= N^5 \end{aligned} \quad (6)$$

The determinant of the system D is:

$$D = \begin{vmatrix} A_1^5 A_1^4 A_1^3 A_1^2 A_1 \\ A_2^5 A_2^4 A_2^3 A_2^2 A_2 \\ A_3^5 A_3^4 A_3^3 A_3^2 A_3 \\ A_4^5 A_4^4 A_4^3 A_4^2 A_4 \\ A_5^5 A_5^4 A_5^3 A_5^2 A_5 \end{vmatrix} \quad (7)$$

The determinant of the system D_1 is:

$$D_1 = \begin{vmatrix} A_1^5 A_1^4 A_1^3 A_1^2 A_1 \\ A_2^5 A_2^4 A_2^3 A_2^2 A_2 \\ A_3^5 A_3^4 A_3^3 A_3^2 A_3 \\ A_4^5 A_4^4 A_4^3 A_4^2 A_4 \\ A_5^5 A_5^4 A_5^3 A_5^2 A_5 \end{vmatrix} \quad (8)$$

For the real coefficient of the polynomial parameters, we get:

$$a_4 = \frac{D_1}{D}, \quad (9)$$

and the other coefficients are obtained by replacing the corresponding columns of determinants with the column that includes reliability:

$$a_3 = \frac{D_2}{D}, \quad (10)$$

$$a_2 = \frac{D_3}{D}, \quad (11)$$

$$a_1 = \frac{D_4}{D}, \quad (12)$$

$$a_0 = \frac{D_5}{D}. \quad (13)$$

In order to obtain the most accurate values of polynomial coefficients ($a_4^1, a_3^1, a_2^1, a_1^1, a_0$) in relation to those obtained by an analytical approach, programming was performed to obtain real polynomial coefficients using the mathematical program MATLAB.

Obtaining the exact value of the real coefficients as well as drawing the correlation dependence graph was programmed in the mathematical program MATLAB as follows [28]:

$$x = \left[A_1^1(t)_{A_5} A_1^2(t)_{A_5} A_1^3(t)_{A_5} A_1^4(t)_{A_5} A_1^5(t)_{A_5}\right], \quad (14)$$

$$y = \left[N_{A_5}^1(t) N_{A_5}^2(t) N_{A_5}^3(t) N_{A_5}^4(t) N_{A_5}^5(t)\right]. \quad (15)$$

In order to be able to apply the mathematical model, it was necessary to tabulate the dependence of the magnitudes of the changes in the condition parameters of the operation $A_i^{n=1,\ldots,5} = f\left(N_1^{i=1,\ldots,5}\right)$ from the reliability values (J_{i-e}) in the exploitation period of the performed measurements, Tables 3 and 4.

Table 3. Reliability values of the real coefficients of the polynomial parameter in the function of assembly operation values without applying the control of the parameter condition of the components

Assembly components	Coefficient mark				
	a_4^i	a_3^i	a_2^i	a_1^i	a_0^i
N_1	0	0	0	-0.1728	0.9464
N_2	0	0.06872	0	0	0
R_1	0.00008	0.00672	0.07568	1.70896	0
N_3	0	0.0064	0.06528	0.43304	-1.81136
N_4	0	0.00216	0.02568	0.2384	0.98768
N_5	0	0.00288	0.03328	-0.1537	0.9872
N_6	0	0.00168	0.0808	0.56368	2.25408
N_7	0	0	0	0.52408	0.8
N_8	0	0	0	0.51022	0.7456

Table 4. Reliability values of the real coefficients of the polynomial parameter in the function of assembly operation values with applying the control of the parameter condition of the components

Assembly components	Coefficient mark				
	a_4^i	a_3^i	a_2^i	a_1^i	a_0^i
N_1	0.4368	0.00328	0	0	0
N_2	0.02616	0.01704	0.88592	0.67688	0
R_1	0	0.00712	0.10192	0.07496	0
N_3	0	0.00648	0	0	0
N_4	0.02136	0.00432	0	0	0
N_5	0.0276	0	0	0	0
N_6	0.042238	0.00312	0.78528	0.2916	0.06432
N_7	0	0	0	0	0.73312
N_8	0	0	0	0	0.6913

3.2. Allowed Risk of Mechanical Vibrations

The construction of the diagram was done based on the reliability values for the area of permissible risk and the medium values of the amplitudes of mechanical vibrations at the selected measuring points (Figs. 2-4).

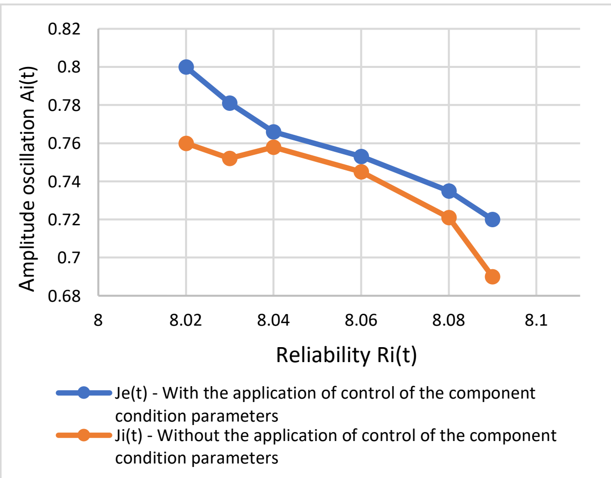

Fig. 2. Dependence reliability diagram in a function of amplitude oscillation for measuring point 1, without and with the application of control of the component condition parameters

These reference curves show the optimal values of the dependence correlation, and based on them, the reliability values can be checked at any time, whether the curve is close to a certain point or is scattered. Based on such an analysis, it is necessary to apply the parameters condition of the component or carry out an overhaul of the component.

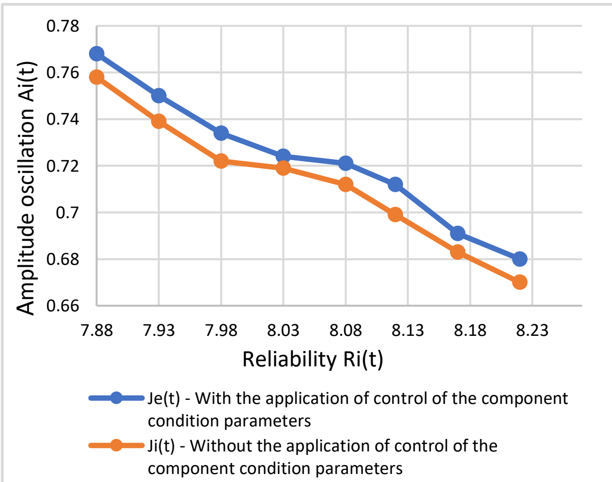

Fig. 3. Dependence reliability diagram in a function of amplitude oscillation for measuring point 2, without and with the application of control of the component condition parameters

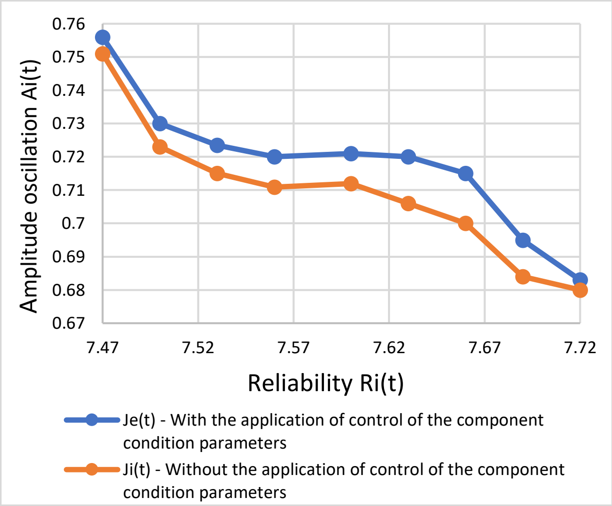

Fig. 4. Dependence reliability diagram in a function of amplitude oscillation for measuring point 3, without and with the application of control of the component condition parameters

Determining the diagnostic parameters was reduced to quantities with known laws from probability theory. The model determines the functional dependence of the double peak amplitudes of turbine and generator shafts.

3.3. Formation of the Universal Optimal Model of Vibrodiagnostics

To form a universal optimal model of vibrodiagnostics, it was necessary to determine all the listed parameters of theoretical and exploitation analysis (which were determined analytically or experimentally), and then connect them in a mathematical form. This was done analytically in the form of transfer functions of the optimal model $O_\eta(t)$ that will define the operation of the analyzed components of the turbogenerator.

The analysis of the model was carried out gradually, in the determination of sub-models according to the selected measuring points for determining the level of mechanical oscillations, and then the block diagram structure of the connection of the sub-models was carried out.

When solving this model, reductions were made to obtain the optimal reliability function $H_p(t)$. The model block diagram reliability of the constituent components is shown in Fig. 5 (where: M_1 - measuring the point of oscillation level on the turbine shaft, M_2 - measuring the point of temperature measurement on bearings and M_3 - measuring point at bearing weariness and $N_1 - N_8$ - assembly components).

Measuring point 1, includes components (N_1 and N_2). These are static components so that $\omega_{N_1} = \omega_{N_2} = \omega_{R_1} \neq \omega_2$; so the relevant speed that affects the level of oscillations $\omega_{N_1}(t) = f\left(N_1(t)_{N_1}\right)$ is taken as input speed equal to the shaft speed $\omega_{N_1} = 600$ rpm, $\omega_{N_1} = \omega_{N_2}$.

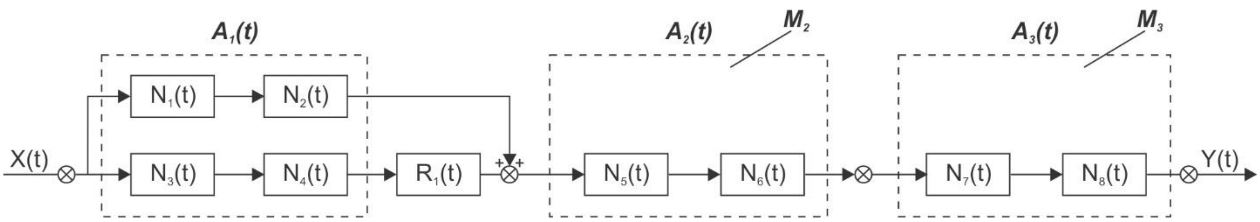

Fig. 5. Model block diagram of the reliability at analyzed components of thermal power plant assemblies TE Kostolac

3.4. Measurement Results

The first part of the constituent component N_1, N_2 and R_1 is:

$$M_{N_1} = \frac{[N_1(t)\cdot N_2(t)]+[N_3(t)\cdot N_4(t)A_1(t)_{N_1}]}{\omega_{N_1}=\omega_{N_3}=f(\omega_1)}t_1 = \frac{[(P_{B_1}\cdot P_{B_2})-R]}{\omega_1}t, \quad (16)$$

$$M_{N_2} = \frac{N_5(t)N_6(t)A_2(t)_{N_2}}{\omega_{n_5}=f(\omega_2)}t_2 = \frac{P_{N_1}(t)}{\omega_2}t, \quad (17)$$

$$M_{N_3} = \frac{N_7(t)\cdot N_8(t)A_3(t)_{N_1}}{\omega_{N_1}=f(\omega_1)}t = \frac{P_{N_7}(t)}{\omega_1}t, \quad (18)$$

$$M_{N_R} = \frac{N_{R_1}(t)\cdot A_1(t)_{N_1}}{\omega_{N_1}=f(\omega_1)}t = \frac{P_{R_1}(t)}{\omega_1}t, \quad (19)$$

where:

$A_1(t)$ - amplitude of oscillation of the working wheel at measuring point 1,

ω_{N_1} - angular speed of assemblies at the measurements point is in function: $A_1(t)_{N_1}$, $A_1(t)_{N_2}$, $A_1(t)_{N_3}$, $A_1(t)_{N_4}$, and $A_1(t)_{R_1}$.

t_1 - time of correct operation of the components.

Determination of partial reliability blocks:

$$A_1(t) = N_1(t)\cdot N_2(t)\cdot N_3(t)\cdot N_4(t), \quad (20)$$

$$O_i(t) = (N_1(t)\cdot N_2(t)N_3(t)\cdot N_4(t) + R_1(t). \quad (21)$$

The first sub-model includes components: sliding bearing N_1 , sliding bearing N_2 , control device R_1, the transformation of the block diagram structure looks as follows, Fig. 6.

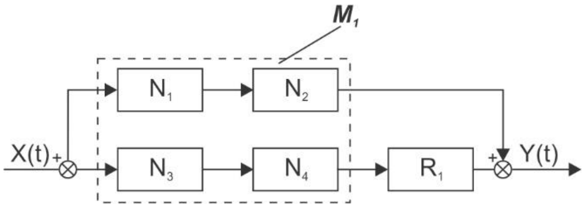

Fig. 6. The assembly of components for monitoring vibrations

This analysis is started with the method of determining the sub-model according to the selected measuring points for determining the level of mechanical vibrations, and then the block diagram structure of the connection of the sub-model according to the movement of the turbogenerator shaft was made.

To perform the general form of the transfer function of the optimal model, it was necessary to determine the expressions from the sub-model N_i, which are included in the locations of the vibration level measurement points S_1 and S_2 (turbo feed pump and turbo oil pump):

$$O_1 = M_{N_1} M_{N_2} M_{N_3} + M_{R_1} = \frac{J_{N_1}(t)A_1(t)_{N_1}}{\omega_{N_1}(t)} t \frac{J_{N_2}(t)A_1(t)_{N_2}}{\omega_{N_2}(t)} t \frac{J_{N_3}(t)A_1(t)_{N_3}}{\omega_{N_3}(t)} t \frac{J_{N_4}(t)A(t)_{N_4}}{\omega_{N_4}(t)} t \frac{J_{R_1}(t)A_1(t)_{R_1}}{\omega_{N_5}} t, \tag{22}$$

where:

$J_{N_i}(t)$ - reliability of components in the useful period of operation.

The result for sub-model 1 is:

$$O_1 = M_1 M_2 M_3 + M_{R.} \tag{23}$$

The model equation of the first part with real coefficients gives the dependence of the reliability of the exciter components in function of the vibration level value at the measuring points:

$$M_1 = \frac{[(P_{B_1} \cdot P_{B_2}) - R]}{\omega_1} \cdot t = \frac{(Q-J)_1(t)}{\omega_1} \cdot t, \tag{24}$$

$$M_2 = \frac{(Q-J)_2(t)}{\omega_2} t, \tag{25}$$

$$M_3 = \frac{(Q-J)_7(t)}{\omega_1} t, \tag{26}$$

$$M_{R_1} = \frac{(Q-J)_1(t)}{\omega_1} t. \tag{27}$$

The result for sub-model 1 is:

$$O_1 = \left(\frac{(Q-J)_{N_1}(t)}{\omega_1} \cdot \frac{(Q-J)_{N_2}(t)}{\omega_2} \cdot \frac{(Q-J)_{N_7}(t)}{\omega_1} \cdot \frac{(Q-J)_{R_1}(t)}{\omega_1} \right) \tag{28}$$

where:

ω_i - number of the shaft spins,

$(Q-J)_i(t)$ - a polynomial with real coefficients that give the dependence of the reliability of the components at measuring point 1.

4. CONCLUSION

The results of the conducted research indicate the practical application and justification of programming the algorithm necessary for the knowledge of mathematical models on optimization of vibrodiagnostic procedures that will provide an analysis of the assembly conditions. Moreover, they represent the assemblies of the turbogenerator, whose state was defined with the input and output value parameters at any time. This model defines the relationship between the periodicity of parameter checks and the signaling tolerance of component parameters while ensuring the desired level of reliability.

The presented research results have scientific and practical justification and are of particular importance for the improvement of vibrodiagnostic procedures as well as preventive maintenance procedures. The scientific justification of the research represents a contribution to the study of parameters and problems of multi-criteria optimization of vibrodiagnostics, which is used in choosing the best method from several possible variants in terms of adopting new models. The optimal solution represents a compromise between wishes and possibilities. The model is usually expressed by the criterion function of the reliability of the components, which for the best solutions should reach the corresponding diagnostic optimization goal.

The advantages of the applied optimal model of vibrodiagnostic procedures of turbogenerator components are:

- Describes and monitors the dynamics of the statistical process of changes in the parameters of the component's condition as a function of the turbogenerator operating time.
- Ensures the required level of reliability of turbogenerator components throughout their lifetime.
- Monitors changes in the identified parameters condition of the assemblies and provides insight into the state of the constituent components of the turbogenerator.
- Preventive settings to prevent failure and replacement of components that are subject to wear, aging, etc.
- The laws of probability are known, which cover the changes in the parameter condition of the components and change it as a function of the turbogenerator operating time.
- The selected diagnostic parameters fully correspond to the parameters condition of the

components and meet the statistical requirements (e.g. diagnostic speed, informativeness, stability, sensitivity, objectivity, etc.).

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