Article citation info:
ŁUKASZEWSKI K. Adaptive reliability structures of heat exchange surface in turbine condenser. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2018; 20 (1): 153–159, http://dx.doi.org/10.17531/ein.2018.1.20.

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ADAPTIVE RELIABILITY STRUCTURES OF HEAT EXCHANGE SURFACE IN TURBINE CONDENSER

ADAPTACYJNE STRUKTURY NIEZAWODNOŚCIOWE POWIERZCHNI WYMIANY CIEPŁA SKRAPLACZA TURBINY PAROWEJ*

In this paper adaptive reliability structures of heat exchange surface in turbine condenser was proved from the angle of effective heat exchange in variable conditions of its exploitation. Then, determinant factors for design and exploitation in assessment of reliability of pipe subsystem in turbine condenser were suggested. The influence of change of scheme of the pipes, constituting the surface of heat exchange, which stems from the matter of regulating the surface in an attempt to both condense the given amount of steam and maintain the given pressure in the condenser in variable conditions of its exploitation on the reliability of the pipe subsystem was determined. The surface of heat exchange is regulated by enabling and disabling the flow of cooling water through given amount of pipes, in a given way, that is by enabling or disabling possible combination of given pipes in given exploitation conditions. An algorithm to assess the reliability of the pipe subsystem in the condenser in given exploitation conditions, means of regulating the surface and up-to-date technical condition was put forward. The reliability of pipe subsystem has a significant influence either on reliability of the condenser while exploited or in the further course, indirectly on sustaining the requested reliability in the power system therein. Effective operation of the condenser in technical power system is performed by sustaining the given pressure of steam condensation, which is vital in maintaining the required energy efficiency of technical power system in variable exploitation conditions. The exemplification of the aspects put forward in the paper pertains to steam turbine condensers.

Keywords: *adaptive reliability structure, reliability, turbine condenser, designing of heat exchangers, exploitation of heat exchangers.*

W artykule wykazano adaptację struktur niezawodnościowych powierzchni wymiany ciepła skraplacza turbiny parowej z punktu widzenia efektywnej wymiany ciepła w zmiennych warunkach jego eksploatacji. Następnie, wskazano istotne uwarunkowania projektowo-eksploatacyjne oszacowania niezawodności podsystemu rur skraplacza turbiny parowej. Wykazano wpływ zmian układów rur stanowiących powierzchnię wymiany ciepła, które wynikają ze sposobu regulacji tej powierzchni w celu skroplenia zadanej ilości pary wodnej i utrzymywania zadanej wartości ciśnienia w skraplaczu w zmiennych warunkach jego eksploatacji, na niezawodność podsystemu rur. Powierzchnię wymiany ciepła reguluje się poprzez włączanie i wyłączanie przepływu wody chłodzącej przez zadaną liczbę rur, w określony sposób tzn. poprzez włączanie albo wyłączanie możliwych kombinacji określonych układów rur w zadanych warunkach eksploatacyjnych. Przedstawiono algorytm oszacowania niezawodności podsystemu rur skraplacza względem określonych warunków eksploatacyjnych, sposobu regulacji tej powierzchni i aktualnego stanu technicznego. Niezawodność podsystemu rur ma istotny wpływ na niezawodność skraplacza turbiny parowej w czasie jego eksploatacji, a dalej pośrednio na utrzymywanie wymaganej niezawodności systemu energetycznego, w którym występuje. Efektywne funkcjonowanie skraplacza w technicznym systemie energetycznym jest realizowane poprzez utrzymywanie zadanego stałego ciśnienia skraplania pary wodnej, co jest istotne z punktu widzenia utrzymywania wymaganej sprawności energetycznej technicznego systemu energetycznego w różnych warunkach eksploatacyjnych. Egzemplifikacja zawartych w pracy zagadnień odnosi się do rurowych skraplaczy turbin parowych.

Słowa kluczowe: *adaptacyjna struktura niezawodnościowa, niezawodność, skraplacz turbiny parowej, projektowanie wymienników ciepła, eksploatacja wymienników ciepła.*

1. Introduction

The aim of the paper is to prove adaptive reliability structures of heat exchange surface, which stems from the matter of regulating the surface in order to maintain effective process of heat exchange by sustaining the requested pressure of steam condensation in variable exploitation conditions, which determines changes in the pipe system of the condenser and involves assessment of reliability of its surface of heat exchange.

Adaptive reliability structures of surface of heat exchange (pipe subsystem) are the reliability structures, which are altered in the course of adjusting the pipe system to the actual exploitation conditions of the condenser in the power system.

Having delved into the current state of the art with IT data bases (Science Direct, Knovel, Nauka Polska, BazTech, google) it was concluded that there has been no algorithm for assessing reliability of surface of heat exchange of steam turbine condenser which would include regulation of the surface in order to exchange the heat effectively and sustain the requested pressure of steam condensation in variable exploitation conditions, which has a significant influence on the quality of the technical power system exploitation, in which the condenser is a part.

Publication [10] shows that sustaining given pressure of steam condensation in the condenser in variable conditions is vital for maintaining requested power efficiency of the technical power system. The aforementioned publication puts forward a particular technical solu-

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** tion, which comes to proper division of the heat exchange surface of the condenser at the stage of its design (a particular number of non-adjustable parts of surface and one part of regulated surface of heat exchange), as well as the setup of the part while being exploited. Such technical solution while the condenser is exploited in the steam power system enables effective regulation of the flow of the water cooling the condenser. The regulation then not only allows for a particular heat exchange between the fluids, but also considers relations among the velocity of the cooling water flow, the erosion and deposition of pollutants on the surface of heat exchange as well as the costs of pumping the cooling water.

In publications [2, 8] the influence of exploitation conditions of turbine steam condensers on power plant efficiency was proved.

The method of designing technical heat exchangers in power systems with regard to requested reliability of them was included in [12, 13]. In methods of designing heat exchangers, including steam turbine condensers described in publications [3-5,7,9,12,13,16-18], the surface of heat exchange is treated as a one, non-adjustable composition (element).

Publication [11] includes the problems of assessing the reliability of the exchanger and heat exchangers. It is possible to determine the models of reliability heat exchangers structures on the basis of the models of basic reliability structures of technical objects, included i.a [6,14].

Sources lack the presence of adaptive structures of reliable surfaces of heat exchange in steam turbine condensers, which may be caused by the means of regulating these surfaces to maintain the given pressures of condensation of the steam in variable exploitation conditions due to exploitation of technical power systems, of which they are a part.

As concerns the aim of the paper and the research into the current state of art the following problem recurs: how to sustain the requested reliability of the steam turbine condenser while it is exploited to a given time?

2. Designing process of reliability structures of heat exchange in the condenser

At the stage of designing of the steam turbine condenser, its reliability model is created $R_{wc}(t)$, taking into consideration applications in technical power system, possible kinds of damages to it as well as the construction of the condenser in accordance with the method included in publication [12]. That is, $R_{wc}(t)$ reliability model for the condenser depicted in figure 1 may be referred to as a serial structure of reliability of subsystems of given elements, i.e. each of tube sheets $R_{1,i}(t)$, each of covers $R_{2,i}(t)$, the shell $R_3(t)$, each of the ith of nth number of pipes $R_{4,i}(t)$, each of the seals $R_{5,i}(t)$, each ith of mth number of connecting screws $R_{6,i}(t)$, system of regulation of the surface of heat exchange $R_{7,i}(t)$ (system of adjusting the valves shutting off the flow of cooling water through given pipes of the condenser).

The reliability model $R_{ps,r}(t)$ of pipe subsystem, which refers to the algorithm in figure 1, is determined with serial reliability structure of nth number of pipes:

$$R_{ps,r}(t) = [R_{4,i}(t)]^n \,. \tag{1}$$

Model (1) is defined within given exploitation conditions: maximal value of the heat stream $\dot{Q}_{1,\max}$ of condensation of the steam in the condenser, minimal value of the overall heat transfer coefficient $k_{i,\min}$ (through the surface of heat exchange with depositions), maximal value of temperature $T'_{2,\max}$ of cooling water on the input of the condenser. In these conditions while the condenser is being exploited, the flow of cooling water through all the pipes is enabled.

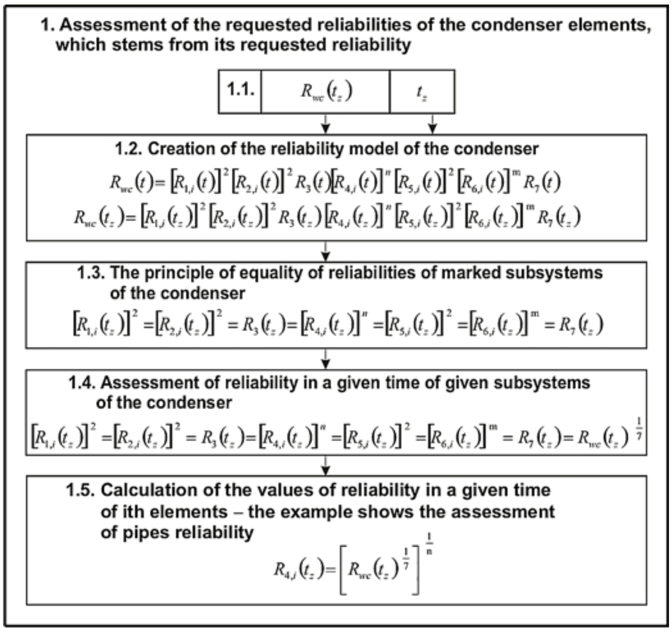

Fig. 1. The algorithm of assessing expected reliabilities of elements of the condenser due to assumed reliability of the condenser (the formula in blocks 1.4 and 1.5 is due to transformation of reliability of the condenser into desirable pipes reliabilities - publication [12] involves the description).

The next significant stage of condenser design is the division of heat exchange surface with regard to anticipated, typical exploitation conditions as present in paper [10]. Both insights allow to assume the following reliability model of pipe subsystem $R_{ps,r}(t)$:

$$R_{ps,r}(t) = R_R(t) R_{NR}(t) \,, \tag{2}$$

in which $R_R(t)$ stands for the reliability model of pipes subsystem of an adjustable number of pipes, and $R_{NR}(t)$ stands for the model of reliability of pipe subsystem, consisting of a number of mth pipe systems with a particular number of enabled and disabled pipes in these systems.

In the first row, it is considered how to divide the surface of heat exchange of the condenser in terms of typical, anticipated states of exploitation of the condenser due to maximize heat exchange efficiency. Thus, in this way a particular way of regulating the heat exchange surface is implicated, that is for given exploitation conditions, the flow of cooling water (with optimal value of flow velocity) is enabled through minimal number of pipes so as to sustain requested and constant pressure of steam condensation. The next implication revolves around creating particular reliability structures of pipe subsystem and implementing them into the $R_{ps,r}(t)$ model. As a result, $R_R(t)$ model is determined with a serial-parallel structure and hence is a part of n_R number of pipe subsystem.

The subsystem is a proper combination of the structure as for the grading of enabling and disabling a given nth number of pipes out of n_R number in given systems in given exploitation conditions, in which $p=n_R-n$:

$$R_R(t)=\prod_{i=1}^{n} R_{R,1,i}(t)\{1-\prod_{j=1}^{p}[1-R_{R,1,j}(t)]\}\ , \tag{3}$$

while n= $n_{R,1}$ then:

$$R_R(t)=\prod_{i=1}^{n} R_{R,1,i}(t)\ , \tag{4}$$

and, while p= $n_{R,1}$:

$$R_R(t)=\{1-\prod_{j=1}^{p}[1-R_{R,1,j}(t)]\}\ , \tag{5}$$

in case the pipe subsystem is adjusted by enabling single pipes, then function $R_{R,1,i}(t)=R_{R,1,j}(t)=R_{4,i}(t)$.

The $R_{NR}(t)$ model may also be determined with the serial-parallel structure and it makes the pipe subsystem of n_{NR} number of pipes. Consequently, the subsystem makes a proper combination of the structure as for grading of enabling and disabling given mth pipe systems, where $k=m_{NR}-m$ in given exploitation conditions:

$$R_{NR}(t)=\prod_{i=1}^{m} R_{NR,1,i}(t)\{1-\prod_{j=1}^{k}[1-R_{NR,1,j}(t)]\}\ , \tag{6}$$

while $m= m_{NR,1}$

$$R_{NR}(t)=\prod_{i=1}^{m} R_{NR,i}(t)\ , \tag{7}$$

or, while $k=m_{NR}$:

$$R_{NR}(t)=\{1-\prod_{j=1}^{k}[1-R_{NR,1,j}(t)]\}\ , \tag{8}$$

in case if mth systems of n-numbered pipes are adjusted than functions $R_{NR,1,i}(t)=R_{NR,1,j}(t)=[R_{4,i}(t)]^n$.

The next step is to consider the division of the surface of heat exchange with regard to typical, assumed exploitation states of the condenser due to maximum reliability $R_{ps,r}(t)$ of pipe subsystem in random configuration of enabling and disabling particular pipe systems while sustaining the requested pressure in the condenser. In such approach, the models $R_R(t)$ and $R_{NR}(t)$ are defined with a threshold reliability structure of *k-out-of-n* type since there is no need to retain the grading to enable and disable particular pipe systems (assuming identical reliability functions of elements of the structure):

$$R_R(t)=\sum_{n=1}^{n_{R,1}}\binom{n_{R,1}}{n}\left[R_{R,i}(t)\right]^n\left[1-R_{R,i}(t)\right]^{n_{R,1}-n}\ , \tag{9}$$

and:

$$R_{NR}(t)=\sum_{m=1}^{m_{NR}}\binom{m_{NR}}{m}\left[R_{NR,i}(t)\right]^m\left[1-R_{NR,i}(t)\right]^{m_{NR}-m}\ . \tag{10}$$

3. The reliability structures of heat exchange surface in exploitation

Figure 2 below presents the algorithm to assess reliability $R_{ps,r}(t_i)$ of pipe subsystem in a given time t_i of exploitation of the condenser, which includes the following change of values in given time spans $[t_{i,\min}, t_{i,\max}]$: stream of heat $\dot{Q}_i$ transferred in the condenser, temperature of $T'_{2,i}$ cooling water on the input of the condenser, the number of pipes or change of the number of enabled pipes $\sum_{i=1}^{m} n_{NR,i}+n_{R,i}$ (with the cooling water flow), which has an influence on heat transfer efficiency, the number of disabled pipes $n_{e,p,i}=\sum_{i=1}^{m}(n_{NR,i}-n_{NR,u,i})+(n_{R,i}-n_{R,u,i})$ (u index) from the exploitation ("jammed"), the pollution of pipe surface as well as the possible air mass content in condensation of steam by calculating the value of overall heat transfer coefficient $k_{e,p,i}$ in given time (problems of ridding of the air in the condenser are not discussed in the paper and hence treated as background problems).

This allows for assumed regulation of the heat surface with regard to a given effective transfer heat $\dot{Q}_i$ in given time spans t_i considering the assessment of pipe subsystem reliability $R_{ps,r,e,i}(t_i)\in[R_{ps,r,e,0}(t_{i,\min}), R_{ps,r,i}(t_{i,\max})]$ in these time spans basing on actual reliability nth pipes $R_i(t_i)$, which stems from function $R_i(t)=f(t_i)_{\{CI_{e,i},W_{e,i},W_{ru,e,i}\}}$. The values of quantities from the sets $CI_{e,i},W_{e,i},W_{ru,e,i}$ defines respectively the identification features of ith elements of the condenser, conditions of exploitation of these elements and kinds of their damages (publication [12] describes $CI_{e,i},W_{e,i},W_{ru,e,i}$ in detail).

The algorithm afterwards may either be treated as an operational tool to verify the function of reliability of pipes $R_i(t)=f(t_i)_{\{CI_{e,i},W_{e,i},W_{ru,e,i}\}}$, implemented at the stage of design, or provide opportunity to alter (update) the reliability function at the stage of the condenser exploitation.

While the condenser is being exploited in technical power system, the following values are monitored: pressure p_1 of steam condensation in the condenser and average velocity w_2 of the flow of cooling water through the condenser pipes, which indicate the efficiency of heat transfer with regard to both assumptions as for the steam turbine operation and economic reasons (the cost of pumping the cooling water). This gives ground, according to the algorithm from figure 2., to assess the exploitation surface $A_{e,i}$ of heat transfer and mass cooling water flow volume $\dot{m}_{2,i}$ through particular system of pipes. Subsequently, the electrical conductivity of the condensate Γ is being constantly monitored. In case the value of the conductivity is below the admissible value, reliability structure of pipe subsystem $R_{ps,r}(t_i)$. needs to be redefined.

Otherwise, if Γ value is higher than admissible, it may cause damage to the pipe (a burst). In such circumstances, different system of pipes needs to be implemented urgently: $n_{e,p,i}=\sum_{i=1}^{m}(n_{NR,i}-n_{NR,u,i})+(n_{R,i}-n_{R,u,i})$. Newly designated value of the surface of heat exchange $A_{e,i}$ is then examined whether it provides effective heat transfer in given exploitation conditions. It must be stressed that only systems with given number of pipes do have an influence on the process of heat transfer. The velocity of the cooling water flow through the pipes may be increased from above the optimal value to the maximum admissible value $w_{2,i} + \Delta w_{2,i} \le w_{2,\max}$ and is performed in case bigger number of pipes needs to be enabled than this would result from sustaining optimal cooling water flow after damage in a particular number of pipes. This aims to sustain requested pressure in the condenser p_1 ($R_i(t) = f(t_i)_{\{CI_{e,i}, W_{e,i}, W_{ru,e,i}\}}$ function is estimated for a given maximal interval of value of cooling water velocity $w_{2,i} \in < w_{2,opt}, w_{2,\max} >$ [m/s]).

Increasing the value of the pressure of condensation in the condenser $p_{1,p,i}$ to maximal admissible value $p_{1,p,i} + \Delta p_{1,i} \le p_{1,\max}$, which is the result of the decrease in the heat stream transferred in the condenser $\dot{Q}_{1,\min}$ and the decrease of effective power $N_{e,p,i}$ in the steam turbine, results from the assumed condition of the seal flow of the cooling water through particular pipe system. Ultimately, the condenser should be excluded from exploitation and either include another one or shut down the power system and thus cease to exploit it. The enumerated actions are determined by functioning of a power system in given time of the condenser operation.

It is assumed that experimental researches of ith pipes have been conducted in order to estimate the reliability function $R_i(t) = f(t_i)_{\{CI_{e,i}, W_{e,i}, W_{ru,e,i}\}}$ in given ith time intervals $0 \le t_i \le t_{i,\max}$ by the pipe producers. The researches include the $CI_{e,i}$ characteristics, identifying ith pipes of the condenser, exploitation conditions of the pipes $W_{e,i}$ and the damages thereof $W_{ru,e,i}$ (the scope and value of damage is determined and hence the pipe is considered damaged if the determined values are exceeded).

Values of reliability of pipes $R_i(t_z)_{\{CI_{e,i}, W_{e,i}, W_{ru,e,i}\}}$ in given time t_z are read with the use of reliability function $R_i(t) = f(t_i)_{\{CI_{e,i}, W_{e,i}, W_{ru,e,i}\}}$ of ith pipes. This allows to introduce and implement the values of reliability to models of particular reliability systems of pipe subsystem and calculate reliability of the subsystem in given time and given exploitation conditions.

In case that ith number of pipes have been damaged, they are replaced with ones of the same kind. In case the difference among their real value of reliabilities and the values obtained from the implemented functions $R_i(t) = f(t_i)_{\{CI_{e,i}, W_{e,i}, W_{ru,e,i}\}}$ exceeds the admissible value, new (updated) reliability functions $R_i(t) = f(t_i)_{\{CI_{e,i}, W_{e,i}, W_{ru,e,i}\}}$ are to be estimated on the basis of monitoring the durability of the pipes (Fig. 2, block 2.7.1) while the condenser is being exploited. Each enabling and disabling the cooling water flaw through given pipes $\sum_{i=1}^{m} n_{NR,i} + n_{R,i}$, out of the group (interval) of a given reliability structures $R_{ps,r}(t_i)$, results in a feedback, while estimating the exploitation of heat exchange surface $A_{e,i}$ as for current monitoring purpose and, having reconsidered the condition suggesting that the reliability value $R_{ps,r}(t_i)$ calculated when the condenser is exploited is equal or higher than assumed admissible reliability $R_{ps,r,dop}(t_i)$ in a given time interval t_i. Subsequently it results also in monitoring current exploitation conditions and forecasting these conditions in further time intervals t_i.

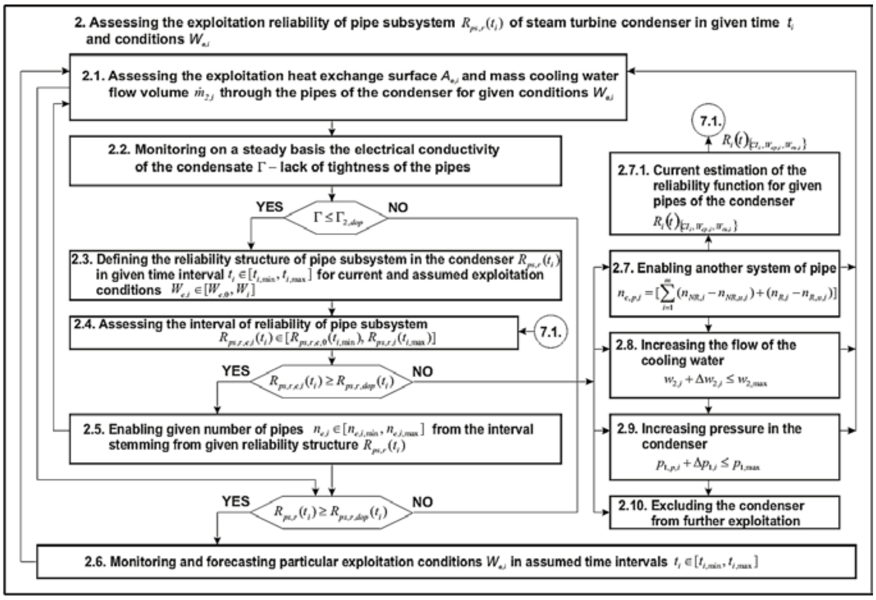

Fig. 2. The algorithm of assessing exploitation reliability of pipe subsystem of steam turbine condenser in given time and conditions

4. Exemplification of the adaptive characteristic of the heat exchange surface in the steam turbine condenser

The calculation example pertains to empirical studies of the damage to the condenser pipes, included in publication [1,15], on the basis of which, normal distribution has been assumed. The parameters of the distribution m=15,7, and σ=6,2 as for 100 pieces of condenser pipes were included into the calculation on the basis of studies of damages to condenser pipes of power units 225MW (publication [15]). According to paper [10] the overall number of pipes (12000) was assumed. Calculations and diagrams were generated with the use of BlockSim software by HBM Prenscia (BlockSim - integrated software allowing for analysis of RBD reliability structures). The example illustrates the calculations of reliability of pipe subsystem with regard to the contents of the paper, in case they include reliability function of pipes made out on the basis of empirical studies of power units condensers. The abridged method for designing heat exchangers of technical power systems with regard to their requested reliability is included in papers [12,13], where means of increasing the reliability of heat exchangers, if necessary, were highlighted.

The pipe subsystem of the steam turbine condenser of 12000 pipes consists of the following pipe systems: $n_{R,1}$=2000, means 20 pipe system 100 pipes each, where the function of reliability of a system may be determined as $R_{R,1,i}(t) = [R_{4,i}(t)]^{100}$ and n_{NR}=10000, where m=5 pipe systems, 2000 each, where consequently the function of reliability of a system may be determined as $R_{NR,1,i}(t) = [R_{4,i}(t)]^{2000}$. There is lack of damaged pipes („jammed"), $n_{NR,u,i}$=0, $n_{R,u,i}$=0.

The first example of calculation (Fig.3) pertains to the application of formulas (11-15) in given exploitation conditions $W_{e,i}$. The latter examples, defined by the number of pipes as follows 6100, 6000, 4100, 4000, 2100, with the flow of cooling water through each, are analogous to the presented formulas (11-15).

The function of reliability $R_{ps,r}(t)$ of pipe subsystem may be defined with the formula (11) if the current exploitation conditions $W_{e,i}$ determine enabling the cooling water flow through 12000 pipes:

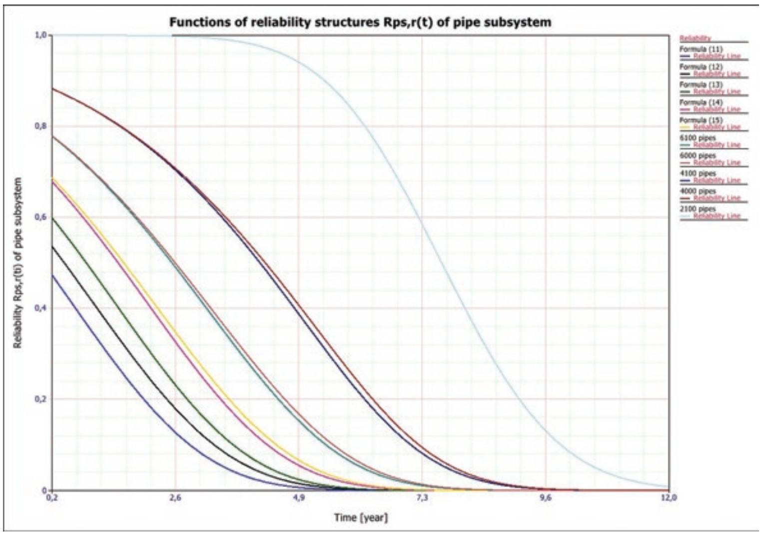

Fig. 3. Functions of reliability structures $R_{ps,r}(t)$ of pipe subsystem

$$R_{ps,r}(t) = \prod_{i=1}^{20} R_{R,1,i}(t) \prod_{i=1}^{5} R_{NR,1,i}(t) \ . \qquad (11)$$

The reliability function $R_{ps,r}(t)$ may be defined with formula (12) if current exploitation conditions $W_{e,i}$ determine enabling the cooling water flaw through 10100 pipes, and 900 pipes are a backup to streams of transferred fluid heat:

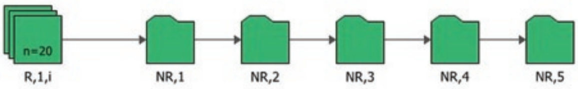

Fig. 4. Flowchart of reliability structure of pipe subsystem – formula (11), where box R,1,i means 20 systems ($R_{R,1,i}(t) = [R_{4,i}(t)]^{100}$) of pipes in serial structure, and sub diagrams NR,1-NR,5 pipe systems ($R_{NR,1,i}(t) = [R_{4,i}(t)]^{2000}$) in serial structure

$$R_{ps,r}(t) = \{1 - \prod_{j=1}^{20}[1 - R_{R,1,j}(t)]\} \prod_{i=1}^{5} R_{NR,1,i}(t). \qquad (12)$$

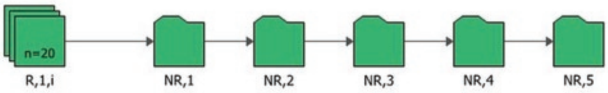

Fig. 5. Flowchart of reliability structure of pipe subsystem - formula (12), where box R,1,i means 20 systems ($R_{R,1,i}(t) = [R_{4,i}(t)]^{100}$) of pipes in parallel structure, and sub diagrams NR,1-NR,5 pipe systems ($R_{NR,1,i}(t) = [R_{4,i}(t)]^{2000}$) in serial structure

The function of reliability may be defined $R_{ps,r}(t)$ with the formula (13) if the current exploitation conditions $W_{e,i}$ determine enabling the cooling water flow through 10000 pipes and 2000 pipes are a backup to streams of transferred fluid heat:

$$R_{ps,r}(t) = \prod_{i=1}^{20} R_{R,1,i}(t) \prod_{i=1}^{3} R_{NR,1,i}(t) \{1 - \prod_{j=1}^{2}[1 - R_{NR,1,j}(t)]\} \ . (13)$$

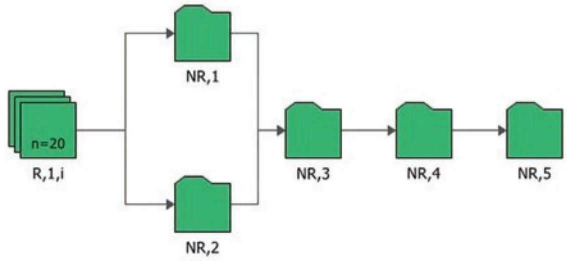

Fig. 6. Flowchart of reliability structure of pipe subsystem – formula (13), where box R,1,i means 20 systems ($R_{R,1,i}(t) = [R_{4,i}(t)]^{100}$) of pipes in serial structure, and sub diagrams NR,1-NR,2 pipe systems ($R_{NR,1,i}(t) = [R_{4,i}(t)]^{2000}$) in parallel structure, and the latter in serial structure

The function of reliability may be defined $R_{ps,r}(t)$ with the formula (14) if the current exploitation conditions $W_{e,i}$ determine enabling the cooling water flow through 8100 pipes and 3900 pipes are a backup to streams of transferred fluid heat:

$$R_{ps,r}(t) = \{1 - \prod_{j=1}^{20}[1 - R_{R,1,j}(t)]\} \prod_{i=1}^{3} R_{NR,1,i}(t) \{1 - \prod_{j=1}^{2}[1 - R_{NR,1,j}(t)]\}. \quad (14)$$

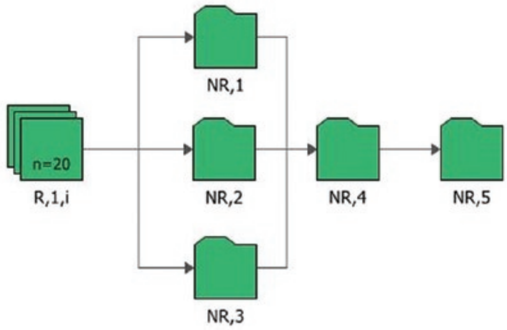

Fig. 7. Flowchart of reliability structure of pipe subsystem – formula (14), where box R,1,i means 20 systems ($R_{R,1,i}(t) = [R_{4,i}(t)]^{100}$) of pipes in parallel structure, and sub diagrams NR,1-NR,2 pipe systems ($R_{NR,1,i}(t) = [R_{4,i}(t)]^{2000}$) in parallel structure, and the latter in serial structure

The function of reliability may be defined $R_{ps,r}(t)$ with the formula (15) if the current exploitation conditions $W_{e,i}$ determine enabling the cooling water flow through 8000 pipes and 4000 pipes are a backup to streams of transferred fluid heat:

$$R_{ps,r}(t) = \prod_{i=1}^{20} R_{R,1,i}(t) \prod_{i=1}^{2} R_{NR,1,i}(t) \{1 - \prod_{j=1}^{3}[1 - R_{NR,1,j}(t)]\} \ . (15)$$

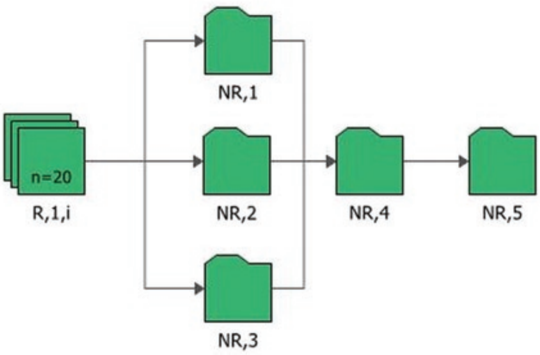

Fig. 8. Flowchart of reliability structure of pipe subsystem - formula (15), where box R,1,i means 20 systems ($R_{R,1,i}(t)=[R_{4,i}(t)]^{100}$) of pipes in serial structure, and sub diagrams NR,1-NR,2 pipe systems ($R_{NR,1,i}(t)=[R_{4,i}(t)]^{2000}$) in parallel structure, and the latter in serial structure

The example illustrated with Figure 3. shows that the reliability $R_{ps,r,e,i}(2)$ of the steam turbine condenser in the second year of exploitation for assumed, considering the ground for effective heat transfer, regulation of the heat exchange surface depending on given exploitation conditions $W_{e,i}$ is the following in respect to Fig.3:

$R_{ps,r}$(t=2)=0,194214; $R_{ps,r}$(t=2)=0,255212; $R_{ps,r}$(t=2)=0,31621; $R_{ps,r}$(t=2)=0,415523; $R_{ps,r}$(t=2)=0,434681; $R_{ps,r}$(t=2)=0,571202; $R_{ps,r}$(t=2)=0,577219; $R_{ps,r}$(t=2)=0,758509; $R_{ps,r}$(t=2)=0,760399; $R_{ps,r}$(t=2)=0,99922.

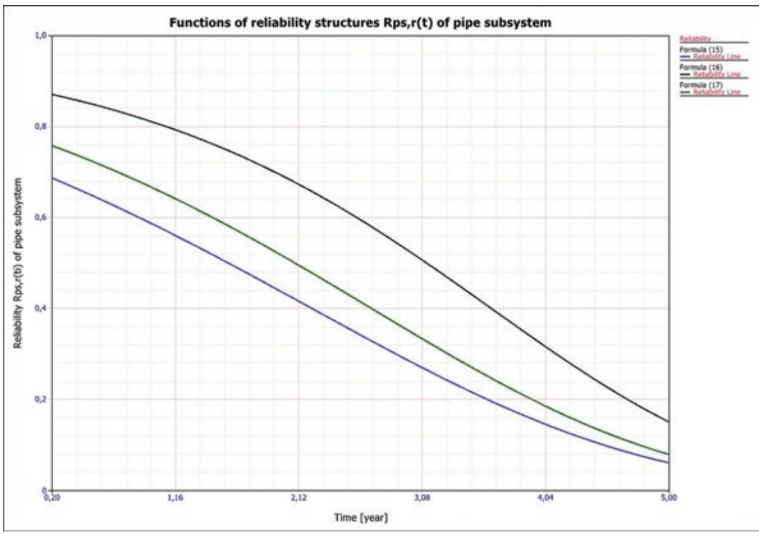

Fig. 9. Functions of reliability structures $R_{ps,r}(t)$ of pipe subsystem

The next example of calculations, illustrated with Fig.9., concerns with application of formulas (15), (16), (17) and given exploitation conditions $W_{e,i}$, which determine enabling the cooling water flow through 8000 pipes of 12000 total.

$$R_{ps,r}(t)=\prod_{i=1}^{20}R_{R,i}(t)\left\{\sum_{m=3}^{5}\binom{5}{m}\left[R_{NR,i}(t)\right]^{m}\left[1-R_{NR,i}(t)\right]^{5-m}\right\}. \quad (16)$$

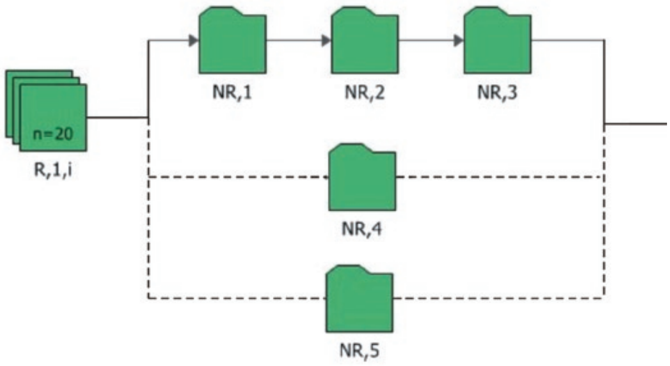

Fig. 10. Flowchart of reliability structure of pipe subsystem - formula (16), where box R,1,i means 20 systems ($R_{R,1,i}(t)=[R_{4,i}(t)]^{100}$) of pipes in serial structure, and sub diagrams NR,1-NR,5 pipe systems ($R_{NR,1,i}(t)=[R_{4,i}(t)]^{2000}$) in structure k-out-of-n

$$R_{ps,r}(t)=\prod_{i=1}^{20}R_{R,i}(t)R_{NR,1,i}(t)\{1-\prod_{j=1}^{2}[1-R_{NR,1,j}(t)]\}\{1-\prod_{j=1}^{2}[1-R_{NR,1,j}(t)]\}\,.(17)$$

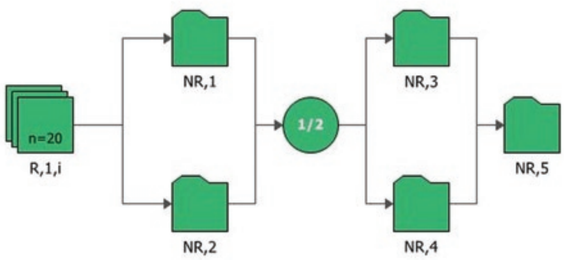

Fig. 11. Flowchart of reliability structure of pipe subsystem - formula (17), where box R,1,i means 20 systems ($R_{R,1,i}(t)=[R_{4,i}(t)]^{100}$) of pipes in serial structure, and sub diagrams NR,1-NR,5 pipe systems ($R_{NR,1,i}(t)=[R_{4,i}(t)]^{2000}$) in serial-parallel structure

The example illustrated with Figure 9. shows that in the second year of exploitation of the steam turbine condenser the reliabilities $R_{ps,r}(t_i)$ of pipe subsystem, defined with formulas (15), (16), (17) equal respectively: $R_{ps,r}$ (t=2) = 0,434681; $R_{ps,r}$ (t=2) = 0,69078; $R_{ps,r}$ (t=2) = 0,514836 in given exploitation conditions.

The calculations allow for the conclusion that the means of regulation of the pipe systems has a significant influence on reliability $R_{ps,r}(t_i)$ of pipe subsystem.

4. Conclusions

It has been proved essential to take into consideration the adaptive property of reliability structure of heat exchange surface both in the process of designing the steam turbine condenser and in the process of its exploitation. The significance of the property is reflected in sustaining the requested value of reliability of the system exploitation and sustaining requested energy efficiency of the technical power system.

By monitoring and forecasting the reliability of the pipe subsystem during exploitation of the steam turbine condenser, the accuracy of estimating the reliability of the condenser is increased.

The algorithm put forward in the paper allows for assumed regulation of the heat exchange surface in respect to effective operating of the condenser in technical power system, considering its current (up-to-date) reliability.

A new approach to estimating the condenser needs to be suggested, involving consideration of regulation of the heat exchange surface, current wear and tear of the pipe system as well as changeable exploitation conditions.

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