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2011

PROCEEDINGS

15th Symposium on Thermal Science and Engineering of Serbia

Sokobanja, Serbia, October 18-21, 2011

University of Niš, Faculty of Mechanical Engineering Niš
Society of Thermal Engineers of Serbia

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EXPLOITATION RESEARCHES OF THE THERMO-ENERGETIC SYSTEM'S AVAILABILITY

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Abstract: Thermo-energetic system, consisting of boiler, steam turbine and three-phase synchronous generator, represents a major power plant component, so delays in the working process of such a systems directly cause delays in work of the power system, or furthermore of complete electro-energetic system of a country. This implies that power plants must have technical solutions that will work give maximum availability and reliability during the process of working. The paper presents the determination of availability and reliability of a thermo-energetic system based on exploitation researches.

Key words: *Thermo-energetic system , Reliability, Maintainability, Availability*

2. INSTRUCTION

Development of the industrial and the nonindustrial complex, as well as development of living standards are in high mutual dependence with the development of energy production and energy consumption. Therefore, any disruption in energy supply has negative consequences in social reproduction.

In a very complex economic and energetic situation in the world as well in Serbia, there is as great a problem finding alternative solutions for providing long-term stable energy supply of any kind, especially electricity. Therefore almost all countries around the globe try to achieve this goal and direct its activities on finding energy reserves, or procedures for the use of new forms of energy and above all - rationalization of energy consumption.

Accordingly the question being asked is: how the availability of the thermo-energetic system can contribute to achieving the tasks being set; giving rise to the importance of availability, exploitation, production planning, design and construction of new thermo-energetic systems as well as the whole powerplant.

3. AVAILABILITY OF THE THERMO-ENERGETIC SYSTEMS

The availability is defined as:

The probability that an item is in state of functioning at a given point in time (point availability) or over a stated period of time (interval availability) when operated, maintained and supported in a prescribed manner.

It is clear from the above definition that availability is a function of reliability, maintainability and supportability factors (Figure 1).

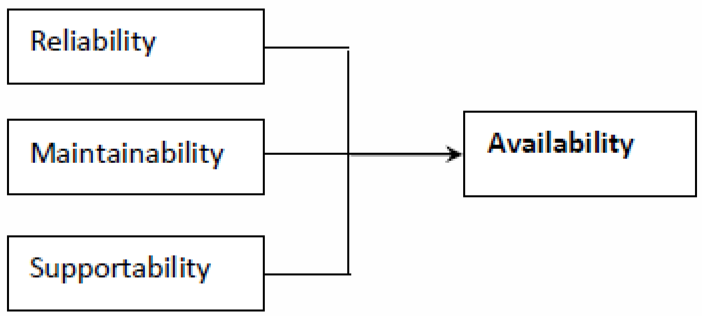

Figure 1 Availability as a function of reliability, maintainability and supportability

Point availability is defined as the probability that the system is in the state of functioning (SoFu) at the given instant of time t. We use the notation A(t) to represent the point availability. Availability expressions for systems can be obtained by using stochastic processes. Depending on the time to failure and time to repair distributions, one can use Markov chain, renewal process, regenerative process, semi-Markov process and semi-regenerative process models to derive the expression for point availability. For example, consider an item with constant failure rate l and constant repair rate m. At any instant of time, the item can be in either the state of functioning (say, state 1) or in the state of failure (say, state 2). As both failure and repair rates are constant (and thus follow exponential distribution), we can use a Markov chain to model the system to derive the availability expression.

Despite the intensive development of the theory of the availability by various authors still there are some differences in interpretation and definitions of basic concepts and laws of this branch of science. However, definition of the availability is as follows:

Availability is the probability that a particular system or device will be able to work during the time regarding to the functioning of the system or device that is properly or part of a system that was repaired in time equal to or less than the total set maintenance time.

The point availability $A(t)$ is given by:

$$A(t) = \frac{\mu}{\lambda + \mu} + \frac{\lambda}{\lambda + \mu} \cdot e^{-(\lambda + \mu)t} \tag{1}$$

Substituting λ = 1/MTTF and μ = 1/MTTR in the previous equation, we get:

$$A(t) = \frac{MTTF}{MTTF + MTTR} + \frac{MTTR}{MTTF + MTTR} \cdot e^{-(\lambda+\mu)t} \qquad (2)$$

Since the working capacity of the system is a variable value, at the beginning of the availability analysis of any technical system, basic conditions and delays are defined. There are three types of the availability characteristic for the thermo-energetic systems:

- availability of time,
- availability of power and
- availability of energy.

The basic system's status, condition and state of the work to a standstill, are influenced with drive, work, and external control mechanisms of the system, whereby the state of work is resulting in the work of the criteria function within the limits of permissible deviations - the stalemate in the state of partial or complete loss of working ability system, or the inability of the system to perform the functions set criteria within the permissible deviations. Occurrence of delays in the system are caused by the effects of different types and their distribution.

Delays in work of the system appear because of:

- standstill of the part of the system or
- standstill because of the external influences.

Both of them can be:

- planned delays and they relate to those delays that occurred at the previously established plan for a certain period of time and
- unplanned, which apply to all delays that occurred unexpectedly in a period of time. Unplanned outages can be enforced and refer to those that are involuntary delays, current and as such can not be dellayable and undellayable or delays may arise because they appeared minimal causes giving rise to deadlock.

Planned or unplanned delays as well as complete failure, and failure that cause the reduction of capacity (the parts of the system) are planned or unplanned interventions on the system appearing as:

- Revision or care, which provides timely halt to the detailed list of works to be performed. It usually provides for the performance of control and diagnostic operations.
- Preventive testing to determine the required characteristics.
- Forced repair or repairs, with repairs made on assemblies and parts or replacing equipment, for which there was an immediate switch off the system or elements.

Also, the delays caused by outside influences can cause a complete failure or a capacity reduction. Delays caused by external influences are caused by:

- standstill of other system in the power plant, which is in connection with our system (the causes of these delays are identical causes of system downtime).
- lack of fuel.
- by the request of the power system, due to the inability of the sale of electricity and hydrology benefits.
- other delays caused by external influences such as the collapse of the system, electrical discharge, work stoppages, natural disasters etc.

3 AVAILABILITY FACTORS

Value of the time availability is determined by 2 factors:

- reliability and
- maintainability.

3.1. Reliability

Today it is generally accepted that the theory of reliability, as a new scientific discipline, examines the legality of occurrence of technical failure of the system.

The technical system is considered as a set of elements, which represent a system performing a single function. In reliability theory, the concept elements (components) of the system refers to parts of the system, whose reliability is calculated integral, and therefore they do not have to be inseparable parts. In determining the reliability of a system, it is necessary to first define the reliability of its elements, and then the whole system.

The term reliability represents the probability of failure-free operation at certain times and certain environmental conditions, ie. probability that the manufacturing process for technical systems take place without interruption and downtime by providing the required deadlines in the implementation of the required production volume, product range and quality (function criteria) with the planned standards of materials, labor and cost for a specific time period and predetermined conditions. As the moments of downtime and the length of the work without delay random variables to be reliable based on the application of probability theory and mathematical statistics, but also has applied information theory, queuing theory, linear and dynamic programming.

To determine the reliability of technical systems its basic indicators are mainly used:

- Cumulative distribution function,
- Probability density function,
- Reliability,
- Failure rate function.

3.2 Maintability

Maintainability can be expressed as the probability that the system will be retained or returned to the state of functionality under the prescribed conditions in a given period of time if the maintenance is in accordance with prescribed procedures. Maintainability is related to:

- principle of simplicity and convenience of the system structure of its composition (assembly, disassembly, easy replace ability, availability, etc..);
- quality of building;
- maintenance conditions;
- integrated system support levels (or degree of organization of functions between the system-environment).

Maintainability is based on the following facts:

- Maintainability is the result of coordination of the design (construction) and operation (operation and maintenance) systems.
- Maintainability must analyze the entire system, not its individual parts.
- Maintainability is determined, predicted, measured and incorporated into the design process and during operation of the system.
- Maintainability is very closely related to the components of effectiveness (reliability, availability).
- Maintainability is a requirement for setting up an efficient system maintenance.
- Requirements that affect maintainability increase productivity (machining-assembly properties of structural systems) and ensure improvement of conditions of exploitation.
- Requests of maintainability influence to apply the innovation system.
- Requests of maintainability also include the maintenance of proper education of employees and others.

To determine the benefits of maintaining the technical systems the following indicators are mainly used:

- Probability density function of minimal maintenance intervals.
- Machinability and non-machinability functions.
- Failure rate function.

Maintenance tasks can be classified into the following three categories:

1. corrective maintenance task,
2. preventive (predictive) maintenance task,
3. conditional maintenance task.

Corrective Maintenance Task

Corrective maintenance task, CRT, is a set of activities, which is performed with the intention of restoring the functionality of the item or system, after the loss of the functionality or performance (i.e. after failure). Figure 2 illustrates typical corrective maintenance task activities. The duration of corrective maintenance task, DMTc, represents the elapsed time needed for the successful completion of the task. Corrective maintenance task is also referred to as an unscheduled or unplanned maintenance task.

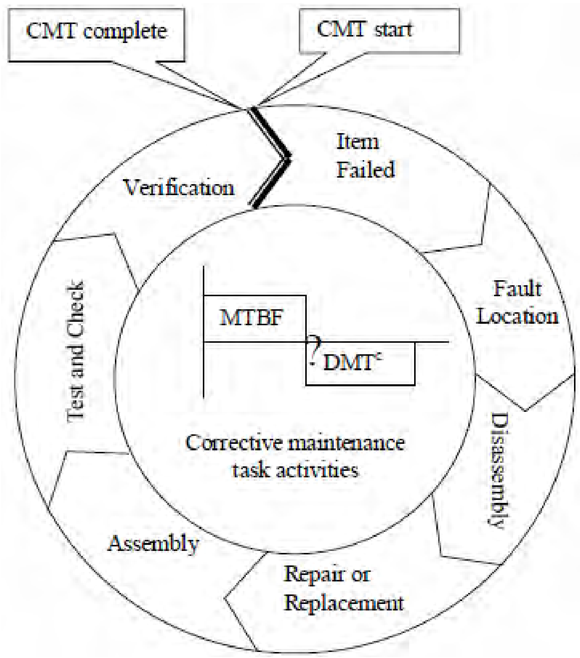

Figure 2 Activities of typical corrective maintenance task

Preventive Maintenance Task

Preventive maintenance task, *PMT*, is a maintenance activity that is performed in order to reduce the probability of failure of an item/system or to maximise the operational benefit. Figure 3 illustrates the activities of a typical preventive maintenance task. The duration of the preventive maintenance task, DMT_p, represents the elapsed time needed for the successful completion of the task.

Preventive maintenance task is performed before the transition to the state of failure occurs with the main objective of reducing:

- The probability of the occurrence of a failure
- The consequences of failure

Common preventive maintenance tasks are replacements, renewal and overhaul. These tasks are performed, at fixed intervals based on operating time (e.g. hours), distance (e.g. miles) or number of actions (e.g. landings), regardless of the actual condition of the items/systems.

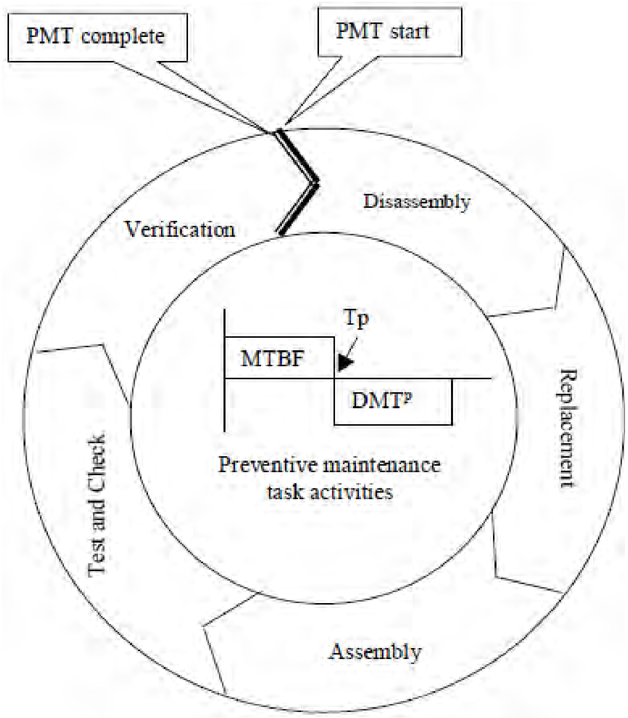

Figure 3 Activities of a typical preventive maintenance task

Conditional (Predictive) Maintenance Task

Conditional maintenance task, *COT*, recognises that a change in condition and/or performance is likely to precede a failure so the maintenance task should be based on the actual condition of the item/system. *COT* does not normally involve an intrusion into the system and actual preventive action is taken only when it is believed that an incipient failure has been detected.

Thus, through monitoring of some condition parameter(s) it would be possible to identify the most suitable instant of time at which preventive maintenance tasks should take place.

Figure 4 illustrates the activities of a typical conditional maintenance. The duration of conditional maintenance task, DMT_m , represents the elapsed time needed for the successful completion of the task. In the past, corrective maintenance and preventive maintenance tasks have been popular among maintenance managers. However, in recent years, the disadvantages of these tasks have been recognised by many maintenance management organisations. The need for the provision of safety, and reduction of the maintenance cost have led to an increasing interest in using conditional maintenance task. Waiting until a component fails may maximise the life obtained from that component but, its failure may cause significant damage to other parts of the system and will often occur at inopportune times causing a disruption to the operation and inconvenience to the users. Routine or scheduled preventive maintenance, on the other hand, may be very convenient but is likely to result in an increase in the amount of maintenance needed because parts will be replaced when they have achieved a fraction of their expected life.

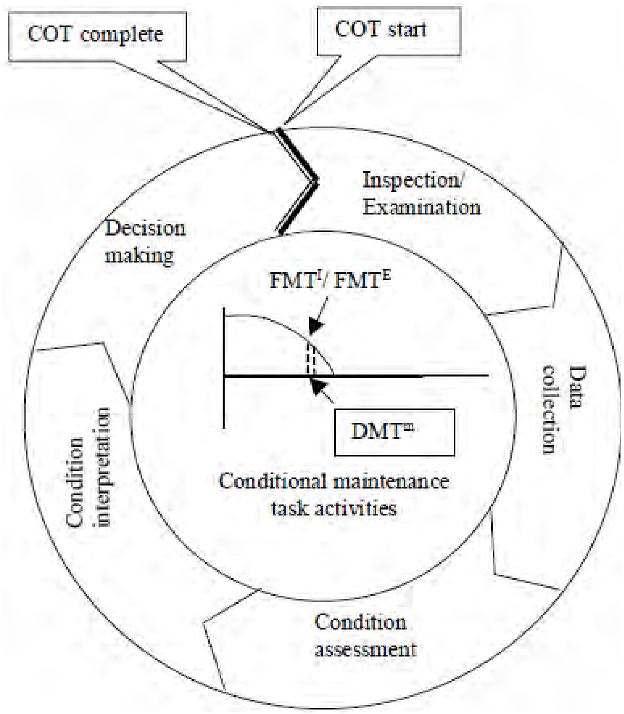

Figure 4. Activities of a typical conditional maintenance task

4. ANALYSIS OF RESULTS AND EXPERIMENTAL RESEARCHES ON THE THERMO-ENERGETIC POWER PLANT NIKOLA TESLA A TPP IN OBRENOVAC

Properties and behavior of all technical systems, as well as TPP Nikola Tesla "A" Obrenovac, by their nature are highly stochastic processes and values. This is, as pointed out, one of the essential features of the concept of reliability. It just explains that all information relating to the reliability of thermal power plant at TPP Nikola Tesla "A" Obrenovac and its main components of random size, subject to certain laws of probability. Because of this, the processing of this information may be performed only with the help of mathematical statistics and probability. Exploiting the thermal power plant operation data of TPP Nikola Tesla A in Obrenovac, and the paper gives the results of these related to the turbine sub-system (Table 1).

Time intervals of work in which are recorded all the data required for processing the reliability and reliability indicators of systems and subsystems are determined by the duration of one year or 8760 hours of work for the period since 1996. year until 2008. year.

Table 1 Experimental results

i	1	2	3	4	5	6	7	8	9	10	11	12	13
T_{ki} [year]	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
T_{i-1} [h]	0	8760	17520	26280	35040	43800	52560	61320	70080	78840	87600	96360	105120
T_i [h]	8760	17520	26280	35040	43800	52560	61320	70080	78840	87600	96360	105120	113880
ΔT_i [h]	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760	8760
T_{ai} [h]	5456	6962	6756	5894	6584	6533	7176	7234	7035	7172	7113	1878	8443
T_{pzi} [h]	2199.25	1078.38	1062.25	2126.36	1345.1	733.54	746.01	862.17	1169.57	908.45	508.39	6430.39	0
T_{nzi} [h]	23.06	4.39	2.09	0.59	112.03	67.51	0	19.36	1	1.07	0	68.48	1.05
T_{rzi} [h]	1081.69	715.23	939.66	739.05	718.87	1425.95	837.99	644.47	554.43	678.48	1138.61	383.13	315.95
T_{ri} [h]	6537.69	7677.23	7695.66	6633.05	7302.87	7958.95	8013.99	7878.47	7589.43	7850.48	8251.61	2261.13	8758.95
$N(\Delta T)_i$	1	1	1	1	3	1	0	3	1	2	0	4	1
$N(T)_i$	1	2	3	4	7	8	8	11	12	14	14	18	19
$n(T)_i$	18	17	16	15	12	11	11	8	7	5	5	1	0
f_i	0.052632	0.052632	0.052632	0.052632	0.157895	0.052632	0	0.157895	0.052632	0.105263	0	0.210526	0.052632
F_i	0.052632	0.105263	0.157895	0.210526	0.368421	0.421053	0.421053	0.578947	0.631579	0.736842	0.736842	0.947368	1
R_i	0.947368	0.894737	0.842105	0.789474	0.631579	0.578947	0.578947	0.421053	0.368421	0.263158	0.263158	0.052632	0
λ_i	0.055556	0.058824	0.0625	0.066667	0.25	0.090909	0	0.375	0.142857	0.4	0	4	$+\infty$
t_{0si} [h]	23.06	4.39	2.09	0.59	37.34333	67.51	0	6.453333	1	0.535	0	17.12	1.05
Σt_{0si} [h]	23.06	27.45	29.54	30.13	67.47333	134.9833	134.9833	141.4367	142.4367	142.9717	142.9717	160.0917	161.1417
$f(t_0)_i$	0.143104	0.027243	0.01297	0.003661	0.231742	0.418948	0	0.040048	0.006206	0.00332	0	0.106242	0.006516
$PO(t_0)_{I\ empirical}$	0.143104	0.170347	0.183317	0.186978	0.418721	0.837669	0.837669	0.877716	0.883922	0.887242	0.887242	0.993484	1
MR %	3.6082	8.7629	13.9175	19.0722	34.5361	39.6907	39.6907	55.1546	60.3093	70.6186	70.6186	91.2371	96.3918
$PO(t_0)_{theoretical}$	0	0.76812	0.94623	0.98753	0.99711	0.99933	0.99984	0.99996	1	1	1	1	1

Marks in table 1:

1. $i-$ the ordinal number of period during system operation
2. $T_{k\,i}$ – calendar time of the i – th interval $i = 1,2,...,n$ $(n = 13)$
3. T_{i-1} – start time of the i – th interval
4. T_i – end time of the i – th interval
5. T_a – engaged time
6. T_{pz_i} – sum of the planned standstills
7. $T_{nz\,i}$ – total sum of the planned standstills
8. $T_{rez\,i}$ – total time in reserve $T_{rez\,i} = \Delta T_i - \left(T_{a\,i} + T_{pz_i} + T_{nz\,i}\right)$
9. $T_{r\,i}$ – medium available time $T_{r\,i} = T_{a\,i} + T_{rez_i}$
10. $N(\Delta T)_i$ – number of delays in the i-th interval

11. $N(T)_i$ – cumulative sum of the delays by the end of the i-th interval

12. $n(T)_i$ – number of usable states at the end of the i-th interval

13. f_i – probabilistic density of downtimes $f_i = N(\Delta T)_i / \sum_1^n N(\Delta T)_i$

14. F_i – unreliability $F_i = \sum_{i=1}^{n} f_i$

15. R_i – reliability $R_i = 1 - F_i$

16. λ_i – failure rate $\lambda_i = N(\Delta T)_i / n(T)_i$

17. $t_{0si} = \frac{T_{nzi}}{N(\Delta T)_i}$ – mean duration of maintenance intervention

18. $t_{0sn} = \sum_{i=1}^{n} t_{osi}$ – total sum of medium duration of maintenance interventions

19. $f(t_0)_i = \frac{t_{0si}}{t_{osn}}$ – density of minimum maintenance interventions

20. $P(t_0)_i = \sum_{i=1}^{n} f(t_0)_i$ – empirical maintainability,

24. $t_{0s} = \frac{1}{n}\sum_{i=1}^{n} t_{osi}$ – median intensity duration of maintenance interventions

24. $\mu_s = \frac{1}{t_{0s}}$ – median intensity of maintenance interventions

23. $P(t_0)_{theoretical} = 1 - e^{-\mu_s \cdot t_o}$ - theoretical maintainability.

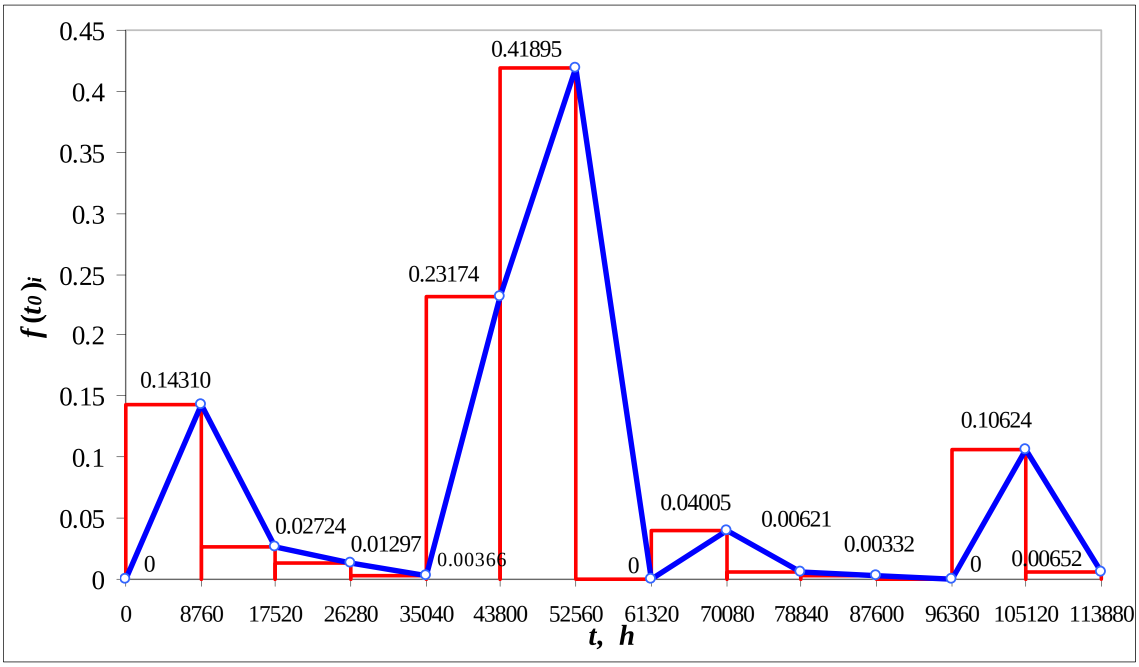

Figure 5 Density of minimum maintenance interventions

$$t_{0s} = \frac{1}{n}\sum_{i=1}^{n} t_{osi} = \frac{1}{13}\cdot 161{,}1417 = 12{,}39\,h$$

$$\mu_s = \frac{1}{t_{0s}} = \frac{1}{12{,}39} = 0{,}0807\,h^{-1}$$

Theoretical maintainability:

$$P(t_0)_{theoretical} = 1 - e^{-0{,}0807\cdot t_o}$$

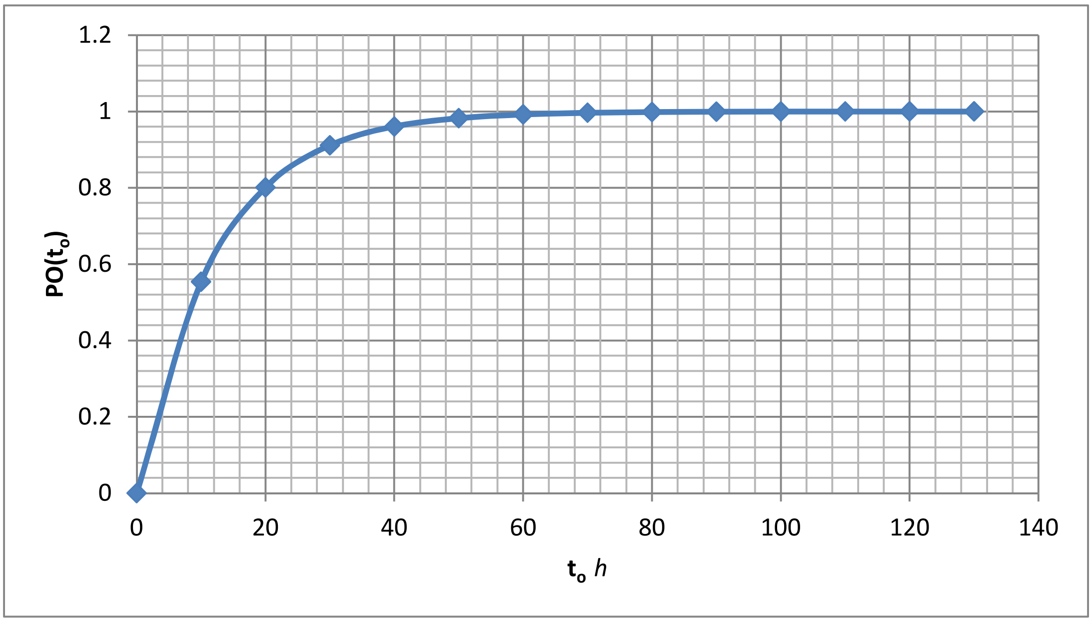

Figure 6 Theoretical maintainability

Function of availability of turbine:

$$A(T)_S = \frac{\mu_S}{\mu_S + \lambda_S} + \frac{\lambda_S}{\mu_S + \lambda_S} e^{-T(\mu_s + \lambda_s)} =$$

$$\frac{0,08068}{0,08068 + 1,5432\cdot 10^{-4}} + \frac{1,5432\cdot 10^{-4}}{0,08068 + 1,5432\cdot 10^{-4}} e^{-T\left(0{,}08068+1{,}5432\cdot 10^{-4}\right)} = 0,998 + 0.001909\cdot e^{-T\cdot 0{,}080834}$$

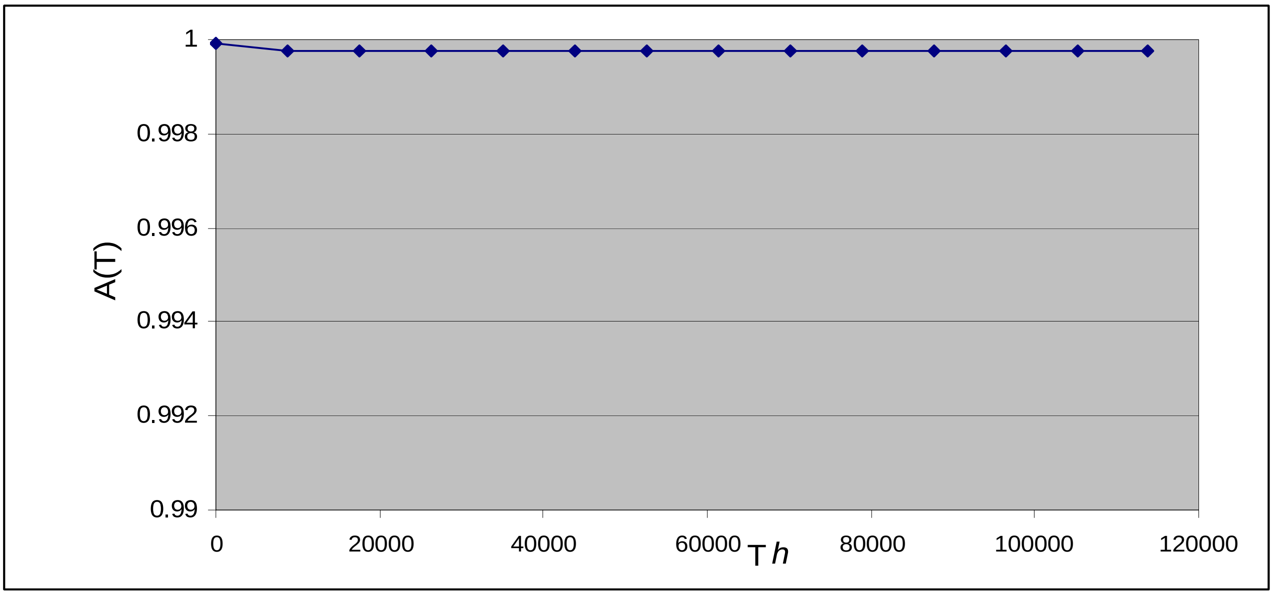

Figure 7 Function of availability

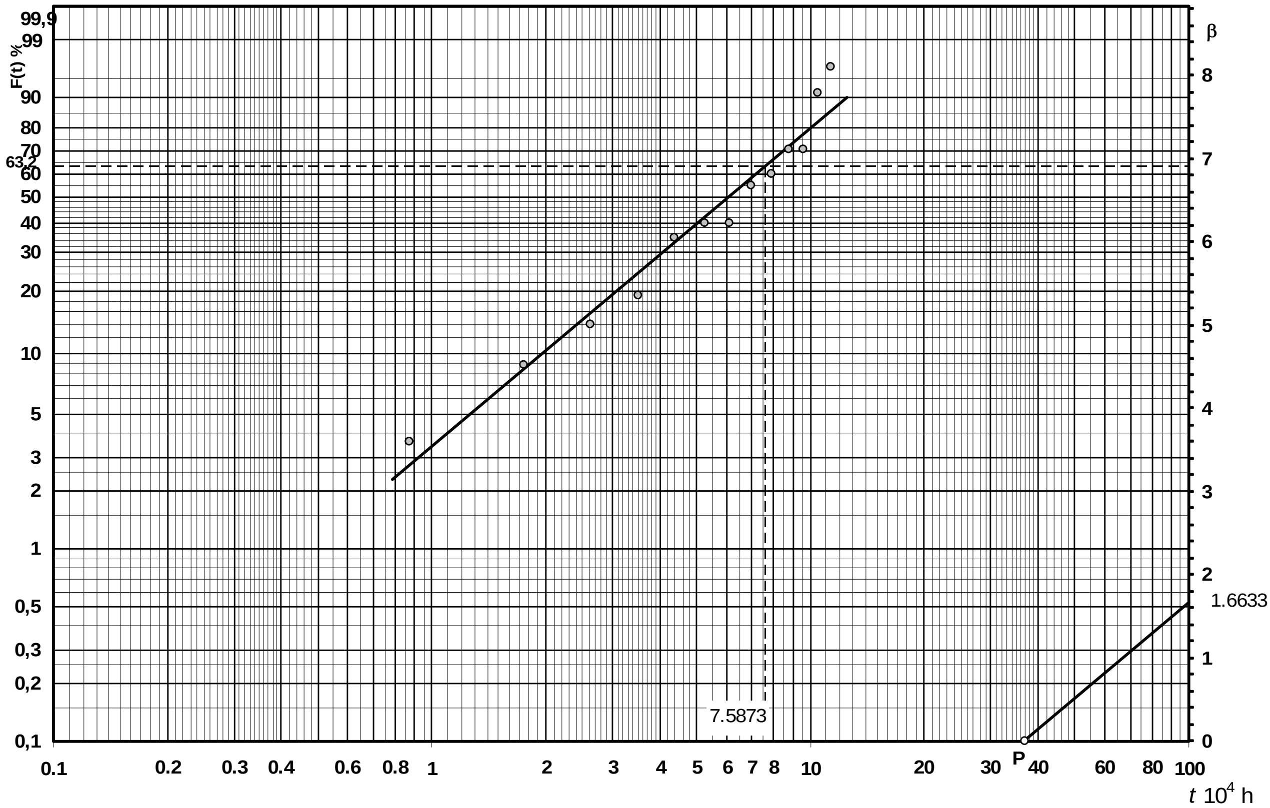

Figure 8 Weibull probability plotting paper

Function of reliability:

$$R(t) = e^{-\left(\frac{t}{75873}\right)^{1,663}}$$

CONCLUSION

Thermo-energetic system, consisting of boiler, steam turbine and three-phase synchronous generator, represents a major power plant component, so delays in the working process of such a systems directly cause delays in work of the power system, or furthermore of complete electro-energetic system of a country.

In paper is give analysis of results and experimental researches on the sub-system turbine of thermo-energetic power plant Nikola Tesla A in Obrenovac.

Data processing functions is determined by the availability, maintainability and reliability of turbine power plant Nikola Tesla A inObrenovac.

Data processing software was used for reliability analysis, developed at the Mechanical Engineering Faculty in Nis.

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