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TIME FOR PREVENTIVE MAINTENANCE OF THE POWER SUPPLY FOR INDUCTION TECHNOLOGY

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Abstract: *Power supplies for induction technology according to the technological process can operate at a constant or variable productivity. Determination of reliability indicators of these supplies is a complex study requiring knowledge of technological process, operating and environment conditions. The time for preventive maintenance is an important parameter of the reliability indicators. This time, at a constant productivity of used power supply, complying with the given warranty period and service costs. In supplies with variable productivity, the allocation of this time depends on the failure rates for each technological process and required working time after preventive maintenance. The results of this study are aimed at determining the reliability parameters of a thyristor power supply for mass heating, depend on productivity schedule.*

Key Words: ***Reliablity/ Maintenance/ Power supply/ Induction heating/***

1. INTRODUCTION

One of the important charecteristics of reliability of electronic equipment is maintainability, and by definition is required to timely troubleshoot the failures through preventive maintenance. An analysis of maintainability is especially important for the power supplies of high cost, which are used in complex and uninterruptible processes.

In forging processes or melting of ferrous or non-ferrous metals, power supplies for metal heating are used, where the induction method is applied. In these induction technologies, the power supplies are of high cost and must provide a continuous manufacturing process and the required productivity. One of the analyses of the maintainability of the power supplies is in relation to reduced costs associated with maintenance and repairs and will satisfy the reliability requirements set.

For the analysis of the maintainability of the power supplies it is necessary to define two indicators - the time for preventive maintenance T_0 and the interval reliability - $P(T_\mu,T_{PS})$.

There are many methods for determining the time for preventive maintenance [1,2]. With constant productivity of the used power supply, the definition of T_0 is in relation to the service costs and the productivity program. In most case, the production program is variable, as well as the productivity for a given period of time of the power supplies. As a whole, it is associated with different electrical and thermal operating and environment conditions.

The purpose of this paper is: *to define the time for preventive maintenance of the power supply for induction technologies, through an analysis of the reliability characteristic – maintainability.*

2. ANALYSIS

With a variable operating mode of a given power supply, i. e., when working with various inductors and productivity, the total failure rate is a variable quality. In this case, to determine the time for preventive maintenance a complicated type of analysis is required and it is related to factors such as: monthly or yearly load of power supply, financial costs or a maintaining a level of reliability. The time for preventive maintenance depends on the required reliability level of the power supply, at which the preventive maintenance should be carried out.

The preventive maintenance is directed to activities that support the system in working condition.

For forging and melting production areas, the operating conditions are characterized by high levels of vibration and mechanical shock, dust and high temperature of the environment. With mechanical shocks, the failures are caused by loosening of the mechanical coupling, connectors and terminals. Failures, caused by the cooling system, are related to leakages and reduced water flow in the cooling radiators. This type of defect, increases the operating temperature of the elements, that are installed on the cooling radiators and respectively increase the failure rates of the elements. The relatively high level of dust with conductive dust, means heaping of conductive layers on circuit boards and components.

For preventive maintenance it is recommended to review the following systems and units and if it is necessary to carry out the appropriate repairs:

- the electrical connections of the power circuits and operational circuits.

- Cooling system - by liquid cooling is need to check the all water connections and circuits for partial reduction of the flow of cooling water.

- Mechanical strengthening of the power elements and printed circuit boards..

- the level of heaping the conductive dust into the elements in the power circuits and into the printed circuit boards of the control systems.

The reliability theory provides, for each production schedule, the reliability indicators of a power supply which guarantee implementation the program. It is necessary to find the optimal time for preventive maintenance and an interval reliability to the end of the production cycle - Fig. 1.

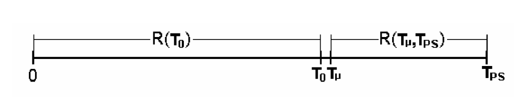


Fig. 1. *Illustration of the time for preventive maintenance and interval reliability*

The parameter T_0 is the time after which the power supply for preventive maintenance will be stopped. Interval from T_0 to T_μ is the time for performing the preventive maintenance and T_{PS} – the time until the end of production schedule.

The interval reliability, indicated with $P(T_\mu, T_{PS})$, shows the reliability of power supply after performed maintenance till the end of the production schedule.

For electronic components in operating conditions the failure rates are distributed by exponential law. For each value of failure rates, in given period of time – t_1, t_2, t_3, t_4, t_5 and t_6, it is known that they are constants:

$$\begin{bmatrix} \Lambda_{T\_PS1}, \Lambda_{T\_PS2}, \Lambda_{T\_PS3}, \\ \Lambda_{T\_PS4}, \Lambda_{T\_PS5}, \Lambda_{T\_PS6} \end{bmatrix} = const. \tag{1}$$

The reliability theory [3] provides possibilities for determining the interval evaluation of the reliability function, given by the following equations – (2) … (5):

$$P(T,x) = \frac{\int_x^{T_0+x} \overline{F}(t)dt}{\int_0^{T_0} \overline{F}(t)dt + \int_{T_0}^{T_\mu} F_\mu(t)dt}. \tag{2}$$

where T_0 – time for preventive maintenance, x – operating time after preventive maintenance, $F_\mu(t)$ – distribution function of maintenance, $F(t)$ - cumulative distribution function(CDF), $\overline{F}(t)$ - is inverse probability function of CDF.

For a given period of time (t, x) the reliability function can be determined by:

$$P(t,x) = \frac{\left[F(t+x) - F(t)\right]}{\overline{F}(t)}. \tag{3}$$

Then the cumulative density function $\overline{F}(t)$ is equal to:

$$\overline{F}(t) = P(t) = \prod_{i=1}^{n} \ell^{\lambda_i . t_i} = \ell^{-\Lambda_T . t}. \tag{4}$$

Where – Λ_T – mean value of failure rate in observed interval (0, T_{PS}).

Assuming that P (t, x) is a decreasing function in x> 0, then a period of time T_0 exists which satisfies:

$$P(T_0;x).\left[\int_0^{T_0} \overline{F}(t).dt + \frac{1}{\mu}\right] - \int_0^{T_0} \left[\overline{F}(t) - \overline{F}(t+x)\right]dt = \frac{1}{\mu}. \tag{5}$$

Where:

$$\mu = \frac{1}{T_\mu - T_0}. \tag{6}$$

After substitution in (3) for $P(T_0, T_{PS})$, using the exponential law is obtained:

$$P(T_0, T_{PS}) = 1 - \ell^{-\Lambda_T .(T_{PS} - T_0)}. \tag{7}$$

The solution to the equation (5) for T_0, will give us the optimal time to preventive maintenance. Optimal time for preventive maintenance depends on parameters, such as failure rate (Λ_{T_PS}) and preventive rate (μ) and time to the end of production cycle:

$$T_0 = \frac{-\ln\left(\dfrac{\dfrac{\Lambda_T}{\mu}}{\ell^{-\Lambda_T .T_{PS}} + \ell^{-\Lambda_T .T_{TS}} .\ell^{-\frac{\Lambda_T}{\mu}}}\right) - \Lambda_T .T_{PS} + \dfrac{\Lambda_T}{\mu}}{\Lambda_T}. \tag{8}$$

Where: Λ_T – mean value of the failure rates in the period of time - (0, T_{PS}).

Then the interval reliability $P(T_0, T_{PS})$ is equal to:

$$P(T_0, T_{PS}) = \frac{\dfrac{\ell^{-\lambda.(T_{PS} - T_0)}}{\lambda}.(1 - \ell^{-\lambda.T_0})}{\dfrac{1}{\lambda}.\left(1 - \ell^{-\lambda.T_0}\right) + \dfrac{1}{\mu}}. \tag{9}$$

The present method can be applied for induction technologies, where the unforeseen suspension will lead to substantial losses. Determination of the optimal time for preventive maintenance and the interval reliability is an opportunity for proper planning of the technological process for providing failure-free operation of the power supply.

A production schedule of forging - press company – "Madara – KOV" Ltd. for a period of one year - 2500 working hours, has been presented.

In Table 1 are shown the failure rates of the power supply for different types of steel parts. They have been calculated in [4, 5].

Table 1. *Produvtivity schedule of an power supply for induction heating*

Steel pieces diameters, [mm]	Operating time t of power supply, [h]		Failure rate Λ_{Th} [FIT]	
ø70	t_1	260	Λ_{T_PS1}	78893
ø80	t_2	300	Λ_{T_PS2}	80380
ø90	t_3	270	Λ_{T_PS3}	88258
ø100	t_4	470	Λ_{T_PS4}	91765
ø120	t_5	650	Λ_{T_PS5}	91765
ø130	t_6	550	Λ_{T_PS6}	95810

It is assumed that the environment condition will change within the adopted changes in the calculation of the total failure rate of the power supply Λ_{T_PS}, for any period of time for the production program.

The power supply operates with a different set of production tools, and has different operating conditions, therefore its failure rates are vary depending on the time of production schedule and type of coils. – Fig. 2.

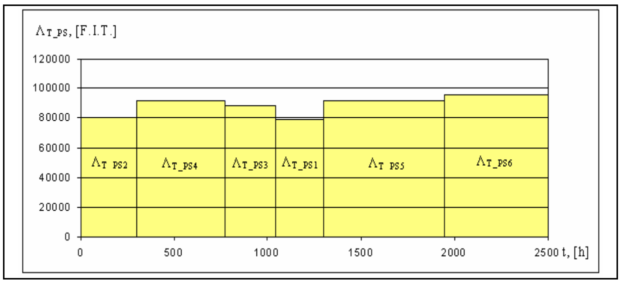
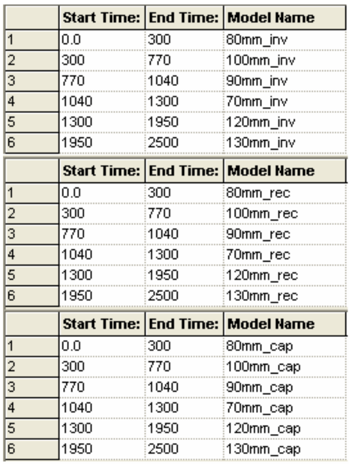


Fig. 2. *Illustration of the productivity schedule*

The results obtained in this form are not applicable to the determination of the time for preventive maintenance due to the differing reliability indicators. Practically,the production program itself is of variable character, too.

According to the purpose set, the theorem for evaluation of the interval reliability for a given period of time is applied, provided that the reliability function is exponentially distributed[3].

With the given values of the operating time with different details - Fig. 3 calculations of the reliability indicators of the power supply have been done, by using the "Fault Tree" method, through the so-called "Mission Profile".



	Start Time:	End Time:	Model Name
1	0.0	300	80mm_inv
2	300	770	100mm_inv
3	770	1040	90mm_inv
4	1040	1300	70mm_inv
5	1300	1950	120mm_inv
6	1950	2500	130mm_inv

	Start Time:	End Time:	Model Name
1	0.0	300	80mm_rec
2	300	770	100mm_rec
3	770	1040	90mm_rec
4	1040	1300	70mm_rec
5	1300	1950	120mm_rec
6	1950	2500	130mm_rec

	Start Time:	End Time:	Model Name
1	0.0	300	80mm_cap
2	300	770	100mm_cap
3	770	1040	90mm_cap
4	1040	1300	70mm_cap
5	1300	1950	120mm_cap
6	1950	2500	130mm_cap

Fig. 3. *Illustration of the "Mission Profile" defined in "Item ToolKit" of an thyristor power supply*

By this method the reliability indicators of the lowest level are introduced - failure rates of the elements in the power circuit taking into consideration the electrical operating and environment condition - fig. 4. The investigated power supply is divided into some functional blocks - "Inverter", "Rectifier", "Load capacitors", "Starting Device" and "Control Automatics". For these functional blocks, the probability of failure of each of them is obtained by using the "Fault Tree Method". To calculate the probability of failure, the program product "ITEM ToolKiT" is used. The probability of failure of each functional block of the power supply is calculated for the given production schedule – "Rectifier" – $Q_{REC}(t)$, "Inverter" - $Q_{INV}(t)$, "Load Capacitors" – $Q_{CIND}(t)$, "Starting Device" – $Q_{SD}(t)$, "Control Automatics" – $Q_A(t)$, according to the load and the time needed to work with this load. The top event in "Fault Tree" gives the probability of failure and the probability of the failure-free operation of the power supply- fig. 4.

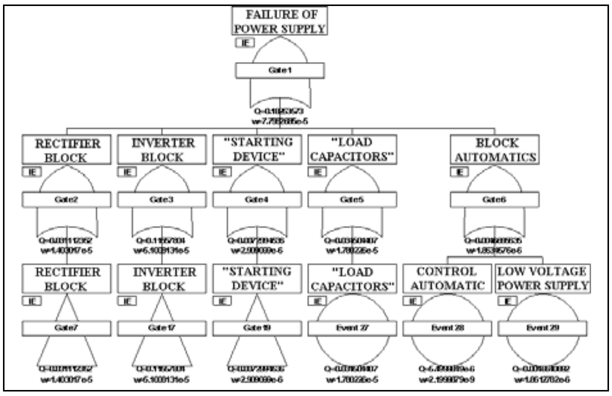


Fig. 4. *Illustration of the "Fault Tree Analysis" of a thyristor power supply for normal operating*

The results obtained for the probability of failure-free operations are reflected in the type of graph - Fig. 5. In this case, at the end of the production program the probability of the failure-free operation of the power supply is $P_{T\_PS} = 0{,}8$ and the probability that it will be interrupted due to failures is very low.

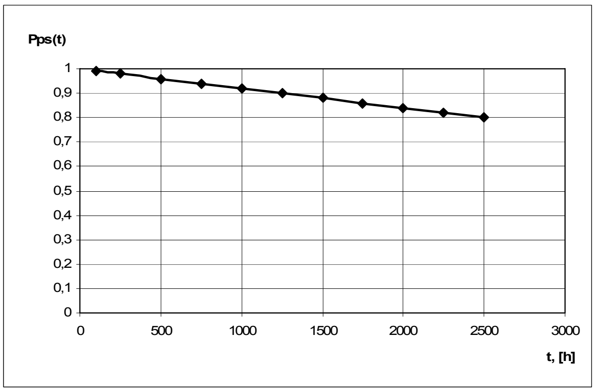


Fig. 5. *Illustration of the reliability function of an power supply depend on time t and productivity schedule*

The analysis and calculations show stable quantitative indicators of reliability for the set time of a given production program under operating conditions within the range of the changes set. In this case the time for preventive maintenance should not be determined, taking into consideration the following practical considerations:

- the calculated failure rates of the power supply determine the reliability level – $P_{PS} = 0{,}80$ at the end of the considered period of time of 2500h.

- The elements and the functional blocks that build the power supply have a level of probability of failure $Q_i < 0{,}05$ - Fig. 4.

From practical experience and the accumulated databases for operational reliability, it has been found that in carrying out of the given productivity schedule, the level of reliability does not match the analysis results.

Agreater number of failures have been observed in comparison with the envisaged ones for the functional blocks and they result from the provisionally adopted constant operating conditions. If the human factor is not taken into account in the analysis of failures, the changed operating conditions are related to:

- the exposed to vibration and mechanical shock, water and electrical connections are loosened.
- the dust level increases and conductive layers are heaped on the circuit boards and components.

By applying the calculation methodology used, possible changes in operating conditions are set. The analysis done by using the "Fault Tree Method" for the same production schedule is implemented at an average forecast temperature rise of the cooling water $T_{A0} = 40^0C$ - Fig. 6.

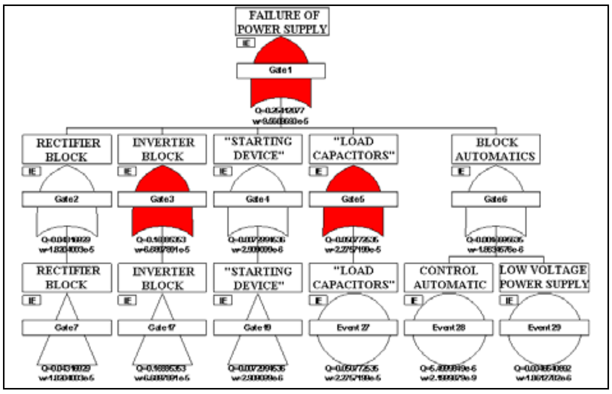


Fig. 6. *Illustration of the "Fault Tree Analysis" of a power supply with failure in cooling system and an average forecast temperature rise* - $T_{A0} = 40^0C$

The results obtained by the "Fault Tree Method" show probability for failure-free operation of the power supply - $P_{PS} = 0{,}744$ and the probability of failure $Q_{PS} = 0{,}256$.

The different functional blocks, which exceeded the given level of probability of failure are:

$$Q_{INV}(T_{PS}) = 0{,}168. \tag{10}$$

$$Q_{CIND}(T_{PS}) = 0{,}06. \tag{11}$$

$$Q_{REC}(T_{PS}) = 0{,}05. \tag{12}$$

In this case, the preventive maintenance is directed to the cooling system and those functional blocks which are connected to it.

The analysis done by using the "Fault Tree Method" is for the same production schedule and failure in cooling system. The reliability indicators have been estimated at an average forecast temperature rise of the cooling water $T_{A0} = 50^0C$ - Fig. 7.

The results obtained by the "Fault Tree Method" show probability for failure-free operation of the power supply – $P_{PS} = 0{,}622$ and the probability of failure $Q_{PS} = 0{,}378$.

In this case, the functional blocks, which are connected to the cooling system are those which have a high probability of failure:

$$Q_{INV}(T_{PS}) = 0{,}271. \tag{13}$$

$$Q_{CIND}(T_{PS}) = 0{,}074. \tag{14}$$

$$Q_{REC}(T_{PS}) = 0{,}067. \tag{15}$$

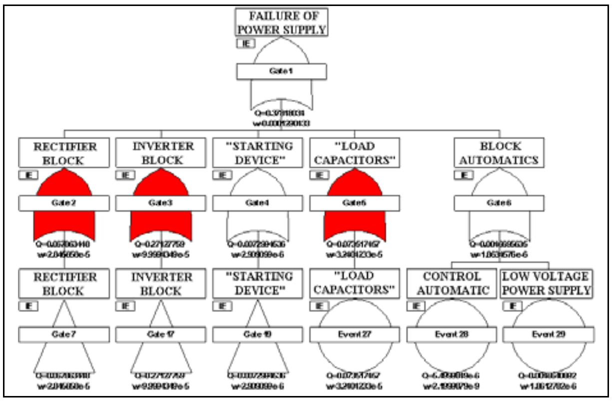


Fig. 7. *Illustration of the "Fault Tree Analysis" of a power supply with failure in cooling system and an average forecast temperature rise* - $T_{A0} = 50^0C$

Figure 8 shows the probability of failure-free operation of the power supply in normal operating conditions – $T_{A0} = 25^0C$, at increased values of the temperature of cooling water – $T_{A0} = 40^0C$ and at the temperature of the cooling water – $T_{A0} = 50^0C$.

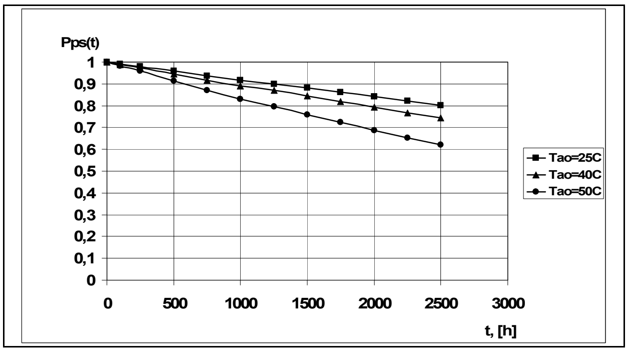


Fig. 8. *Illustration of the reliability function of an power supply depend on time t and productivity schedule for various cooling temperature*

The reliability indicators of the power supply for all three cases have been defined by means of the software program "ItemToolKit".

Under normal operating conditions the probability of failure-free operation of the power supply is:

$$P_{PS}(T_{PS}) = 0{,}80. \tag{16}$$

When the power supply operates with possible deviations from the normal operating conditions and at a forecast temperature rise – $T_{A0} = 40^0C$, the probability of failure-free operation is:

$$P_{PS1}(T_{PS}) = 0{,}744. \tag{17}$$

When the power supply operates with possible failures in the cooling system and at a forecast temperature rise – $T_{A0} = 50^0C$, the probability of failure is:

$$P_{PS2}(T_{PS}) = 0{,}622. \tag{18}$$

The results show an increase in the probability of failure of the power supply of approximately two times.

Temperature changes do not directly cause failures, but their influence is associated with a reduction in the probability of failure-free operation of the elements in the power circuits (thyristors and capacitors).

In case of a failure related to a reduced flow of cooling water, the probability of failure-free operation reaches a level – $P_{PS} = 0,744$. The time for preventive maintenance at the required reliability level of the power supply of $P_{PS} = 0,8$ is calculated by (8):

$$T_{01} = 1886h. \qquad (19)$$

In case of a failure related to a reduced flow in the cooling radiators, the probability of failure-free operation reaches a level – $P_{PS} = 0,62$. The time for preventive maintenance at the required reliability level of the power supply of $P_{PS} = 0,8$ is calculated by (8):

$$T_{02} = 1166h. \qquad (20)$$

In these cases, the following preventive maintenance actions for the power supply have been taken: looking for loosening power connection wires, verification of the electrical wiring, defective hoses in cooling, checking the overheating of elements, checking of all hoses and electrical power connections, control of the cables and connectors for loosening and breaking, removing the conductive dust layers from the power supply, checking of the cooling system, which includes the level of the cooling water, the flow in the hoses and the leakage.

3. CONCLUSIONS

The study of the reliability characteristics by applying modern methods of analysis is applicable to power supplies for induction technology. Maintainability is an especially important characteristic for high costs of capital investment and for complicated and uninterruptible production processes .

In forging operations or melting ferrous or non-ferrous metals, the power supplies have a higher cost and must provide a continuous manufacturing process and the productivity set. The accurate analysis and correct determination of the electrical and thermal operating and environment conditions will determine the correct data for the reliability of a given power supply. In this case, the time for preventive maintenance of the power supply is determined. After implementing the prescribed preventive maintenance actions, the cost of maintenance and repairs will be reduced and the power supply will satisfy the required reliability level.

4. REFERENCES

[1] H. Pham: *"Handbook of reliability engineering"*, Springer Verlag, Sept. 2006. pp. 367-380.

[2] Blischke, W., D. Murthy: *"Case studies in reliability and maintenance"*, New Jersey, John Wiley and Sons, 2003, pp. 85 – 93.

[3] Nakagawa T.,*"Maintenance theory of reliability"*, Springer – Verlag, London, 2005, ISBN 1-85233-939-X, pp. 140 – 144.

[4] Simeonov M., P. Prodanov: *"Reliability Analysis on the Induction Heating Installation using the Fault Tree Method"*, XV^{-th} International Symposium on Electrical Apparatus and Technologies, Proceedings of Siela 2007, Plovdiv, Bulgaria, 2007, Vol. 1, pp. 167 -173.

[5] Prodanov P. I., M. Simeonov, D. Dankov, *"Reliability of an induction heating installation in relation to production schedule"*, Proceedings of PCIM-Europe 2008, Nurnberg, Germany, 2008. pp.179-183.