

DETERMINATION OF THE RELIABILITY MODEL OF COOLING UNIT OF ELECTRO-EROSION MACHINE

LUBOSLAV STRAKA

Technical University of Kosice with a seat in Presov
Faculty of Manufacturing Technologies
Department of Manufacturing Processes Operation
Presov, Slovak Republic

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e-mail : luboslav.straka@tuke.sk

Reliability and safety of technical equipment has an important role in engineering practice. Determining of reliability of complicated technical equipment requires complex analysis and thorough preparation of inputs which means processing of great volume of information. On the basis of available information about operation and records about character of failures of observed equipment, it is possible by applying proper reliability model, to describe mathematical functions of particular reliability indicators in dependence on their operation time. The aim of the paper is to determine empirical reliability model of cooling unit of electro-erosion machine AgieCut 270HSS on analysis of its failures which are registered in the equipment database.

KEYWORDS

reliability model, technical equipment, operation probability, failure element, Weibull distribution

1 INTRODUCTION

During the latest years, more attention has been drawn to an increase of quality and reliability of technical equipment and their components [Biolini 2014]. In case of low quality and reliability, the equipment requires costly maintenance and repairs during operation. Reliability of technical equipment

itself does not define precisely system properties [Krenicky 2015]; it expresses only an estimation of system's longevity [Cacko 2014], probability of failure-free operation and a probability of occurrence of particular types of defects. Reliability is thus a statistical parameter which means that it cannot be ensured for particular equipment [Corny 2013]. In evaluation of system reliability it is necessary to differentiate between failure of component and failure of system (called also a system crash). [Dobrany 2013] System crash is only such failure of its components which causes unacceptable change i. e. hampers system ability to fulfil its required function as a whole.

2 PROCEDURE FOR RELIABILITY MODEL ESTABLISHING

Not all failures occurring in technical equipment [Michalik 2013, Murcinkova 2013] can be classified in terms of an ageing or wear. These are mainly failures caused by external factors e. g. working environment or human factor respectively. These failures may occur with the same probability in new equipment as well as in equipment that has been already operating during many operating hours. Since occurrence of these failures does not depend on operation time t , i. e. during operation their probability of occurrence is constant, these failures were excluded from the reliability model [Janacova 2015].

The paper focuses mainly on operating failures that caused outage lasting more than an operation hour. Analysis was carried out with the aim to assign time data of emergence, course, and its elimination to every failure [Maksimov 2016]. For mathematical description [Mizakova 2014] of functional dependences the exponential and Weibull distribution of random variable was applied. Exponential distribution is suitable type of distribution for description of behaviour of failures that occur randomly and suddenly without previous wear of technical equipment [Prislupcak 2014]. Exponential distribution describes well behaviour of the system in normal operation; on the contrary it is not suitable for system behaviour description in beginning period and in the final period of system life [Zajac 2013]. This period of equipment life appropriately describes the Weibull distribution.

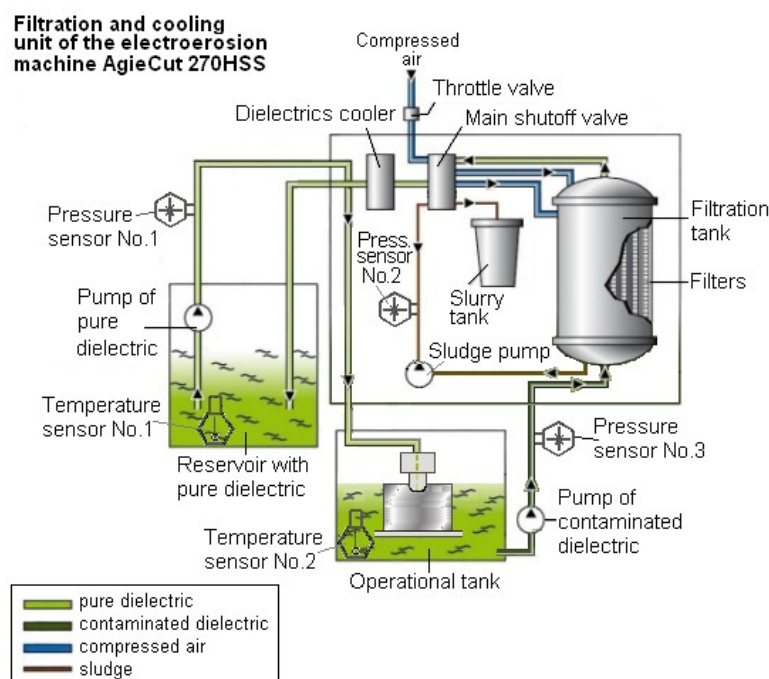


Figure 1. The filtration and cooling unit of electroerosion machine AgieCut 270HSS

The Basic components of the filtration and cooling unit of electroerosion machine AgieCut 270HSS (obr.1):

- dielectric cooler,
- pump of contaminated dielectric,
- pump of pure dielectric,
- sludge pump,
- filtration tank,
- slurry tank,
- throttle valve,
- main shutoff valve,
- pressure and sensor temperature.

2.1 Determination of reliability indicators of elements

One of the basic parameters of reliability of technical equipment is failure rate λ . It gives probability that technical equipment which did not failed during time t will fail in a short time interval dt after time t .

On the basis of recorded data, failure rate of particular components of technical equipment λ_i [h^{-1}] were calculated at first, as reciprocal values of mean time to failure (MTTF), according to formula (1):

$$\lambda_i = \frac{1}{MTTF} \quad (1)$$

Failure density $f_i(t)$ [h^{-1}] it is calculated by formula (2):

$$f_i(t) = \lambda e^{-\lambda t} \quad (2)$$

Probability of failure-free operation $R_i(t)$ of a given constructional unit of electroerosion machine AgieCut 270HSS, at which we assume exponential distribution of failure course,

is determined by formula (3): $R_i(t) = \prod_{i=1}^n e^{-\lambda_i t}$ (3)

Table 1 gives values of mean time to failure (MTTF) recorded in service database of electroerosion machine AgieCut 270HSS, and calculated values of failure rate λ_i and probability of failure-free operation $R_i(t)$ of main parts of unit for filtration and cooling dielectric fluid. Reliability of the constructional unit for filtration and cooling dielectric fluid was determined on the basis of observations over 15,000 hours of operation.

Probability of failure-free operation $R_i(t)$ of particular components constructional unit for filtration and cooling dielectric fluid of electroerosion machine AgieCut 270HSS it is calculated by considering the exponential distribution in the operation time $t = 2000$ h.

Table 1: The values $MTTF$, λ_i and $R_i(t)$ of a given constructional unit for filtration and cooling dielectric fluid by considering the exponential distribution

No.	Component of unit	Mean time to failure (MTTF) [h]	Failure rate $\lambda_i \times 10^{-5}$ [h^{-1}]	Probability of failure-free operation $R_i(t)$
1	Dielectric cooler	15,000	6.66	$R_1 = 0.8751$
2	Sludge pump	7,000	14.0	$R_2 = 0.7514$
3	Pump of contaminated dielectric	11,000	9.09	$R_3 = 0.8337$
4	Pump of pure dielectric	14,000	7.14	$R_4 = 0.8668$
5	Filtration tank	6,000	16.6	$R_5 = 0.7165$
6	Slurry tank	3,000	33.3	$R_6 = 0.5134$
7	Throttle valve	15,000	6.66	$R_7 = 0.8751$
8	Main shutoff valve	12,000	8.33	$R_8 = 0.8464$
9	Pressure sensor No.1-3	8,000	12.5	$R_9 = 0.7788$
10	Temperature sensor No.1-2	9,000	11.1	$R_{10} = 0.8007$

Resulting reliability of unit for filtration and cooling dielectric fluid
 $R_s(t) = 0.039$

Mathematical description of functional dependencies [Michal 2014] with application of Weibull distribution is applied in modelling of reliability properties of parts and systems with non-constant failure rate [Ungureanu 2012]. It is distribution of critical values, overrunning of these values leads to destruction (e. g. steel limit properties – strength, elasticity, etc.). Weibull distribution represents best the distribution of failures that emerge with early failure and ageing of the parts of equipment.

Resulting function of failure probability density $f_i(t)$ and function of failure rate λ_i for Weibull distribution have following forms (4)(5):

- failure density: $f_i(t) = \frac{\beta}{\eta} \cdot \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \cdot e^{\left[-\left(\frac{t-\gamma}{\eta}\right)^\beta\right]}$ (4)

- failure rate: $\lambda_i = \frac{\beta}{\eta} \cdot \left(\frac{t-\gamma}{\eta}\right)^{\beta-1}$ (5)

Probability of failure-free operation $R_i(t)$ of a given constructional unit of electroerosion machine AgieCut 270HSS, at which we assume Weibull distribution of failure course, is determined by formula (6):

$$R_i(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^\beta} \quad (6)$$

where:

β – is parameter of shape, it influences shape of failure rate λ (table 2) and density function $f(t)$;

η – parameter of size, it influences time axis t and thus does not influence shape of the function. Its dimension is influenced by values of mean time to failure (MTTF);

γ – parameter of position indicates minimal longevity of technical equipment (usually in the technical equipment is expressed than 0).

Table 2: Classification of distribution type of random failure parameter in dependence on shape parameter β and failure rate λ

Shape parameter β	Operation period of technical device	Course of failure rate function λ	Distribution type
$0 < \beta < 1$	early failures	decreasing function	Weibull
$\beta = 1$	wearing, ageing	constant linear function	exponential
$1 < \beta < 2$	wearing, ageing	concave increasing function	Weibull
$\beta = 2$	wearing, ageing	linear increasing function	Weibull
$\beta > 2$	wearing, ageing	convex increasing function	Weibull

Since the beginning of failures emergence of technical equipment is considered in time $t = 0$ h from first activation into operation, position parameter has value $\gamma = 0$ in this case. Empirical relations (4); (5) and (6) can then be written in forms:

- adjusted relation for failure density (7):

$$f_i(t) = \frac{\beta}{\eta} \cdot \left(\frac{t}{\eta}\right)^{\beta-1} \cdot e^{\left[-\left(\frac{t}{\eta}\right)^\beta\right]} \quad (7)$$

- adjusted relation for failure rate (8):

$$\lambda_i = \frac{\beta}{\eta} \cdot \left(\frac{t}{\eta}\right)^{\beta-1} \quad (8)$$

- adjusted relation for probability of failure-free operation (9):

$$R_i(t) = e^{-\left(\frac{t}{\eta}\right)^\beta} \quad (9)$$

Table 3: The values $MTTF$, λ_i and $R_i(t)$ of a given constructional unit for filtration and cooling dielectric fluid by considering the Weibull distribution

No.	Component of unit	Values of mean time to failure (MTTF) [h]	Failure rate $\lambda_i \times 10^{-5}$ [h ⁻¹]	Probability of failure-free operation $R_i(t)$
1	Dielectric cooler	15,000	1.77	$R_1 = 0.9823$
2	Sludge pump	7,000	8.16	$R_2 = 0.9216$
3	Pump of contaminated dielectric	11,000	3.31	$R_3 = 0.9674$
4	Pump of pure dielectric	14,000	2.04	$R_4 = 0.9797$
5	Filtration tank	6,000	11.1	$R_5 = 0.8948$
6	Slurry tank	3,000	44.4	$R_6 = 0.6411$
7	Throttle valve	15,000	1.77	$R_7 = 0.9823$
8	Main shutoff valve	12,000	2.77	$R_8 = 0.9726$
9	Pressure sensor No.1-3	8,000	6.25	$R_9 = 0.9394$
10	Temperature sensor No.1-2	9,000	4.93	$R_{10} = 0.9518$
Resulting reliability of unit for filtration and cooling dielectric fluid				$R_s(t) = 0.4207$

Table 3 gives values probability of failure-free operation $R_i(t)$ of particular components constructional unit for filtration and cooling dielectric fluid of electroerosion machine AgieCut 270HSS by considering the Weibull distribution is referred to operation time $t = 2000$ h.

3 RELIABILITY MODELING OF CONSTRUCTIONAL UNIT FOR FILTRATION AND COOLING DIELECTRIC FLUID

In modelling of technical equipment reliability we create reliability model that represents transformation of facility technological structure [Panda 2014]. Reliability model is created in order to formulate functional coherence of technology from a viewpoint of reliability function. The models [Tothova 2015] should facilitate calculation of reliability parameters [Straka 2011]. Any technical equipment that is to be reliability modeled, has to be decomposed into its elements which have various functional [Ruzbarsky 2010] and

technological couplings between them. Majority of reliability tasks are solved by two-state models. It means that there is an assumption concerning every technological equipment component: component is either faultless or has a failure.

3.1 Modeling of reliability indicators of constructional unit by considering the exponential distribution

For given range of reliability of technical equipment can be applied exponential function. It has form (10):

$$y = a \cdot e^{-b \cdot x} \quad (10)$$

By applying variable t with employing of reliability theory it is possible to adjust this formula into form (11):

$$y = a \cdot e^{-b \cdot t} \quad (11)$$

where: y – is failure density $f_i(t)$ [h⁻¹];
 a, b – constant component;
 t – operation time of technical equipment [h].

Exponential function of failure density $f_i(t)$ of particular elements of a given constructional unit for filtration and cooling dielectric fluid it is shown in Figure 2.

Mathematical reliability model (13) of comprising the selected reliability indicators of observed constructional unit for filtration and cooling dielectric fluid is following:

$$R(t) = \prod_{i=1}^n R_i(t) = e^{-\sum_{i=1}^n \lambda_i \cdot t} \quad (12)$$

or formula (13):

$$R(t) = R_1(t) \cdot R_2(t) \cdot R_3(t) \cdot R_4(t) \cdot R_5(t) \cdot R_6(t) \cdot R_7(t) \cdot R_8(t) \cdot R_9(t) \cdot R_{10}(t) \quad (13)$$

3.2 Modeling of reliability indicators of constructional unit by considering the Weibull distribution

For given range of reliability of technical equipment a linear regression function can be applied. It has form (14):

$$y = a + x \cdot b \quad (14)$$

By applying variable t with employing of reliability theory it is possible to adjust this formula into form:

$$y = a + t \cdot b \quad (15)$$

where: y – is failure rate λ [h⁻¹];
 t – operation time of technical equipment [h].

From presented relations it can be concluded that failure rate function λ has two components, namely constant component a when failure rate during observed period does not change, and second linear component $b \cdot t$ which increases in operating time.

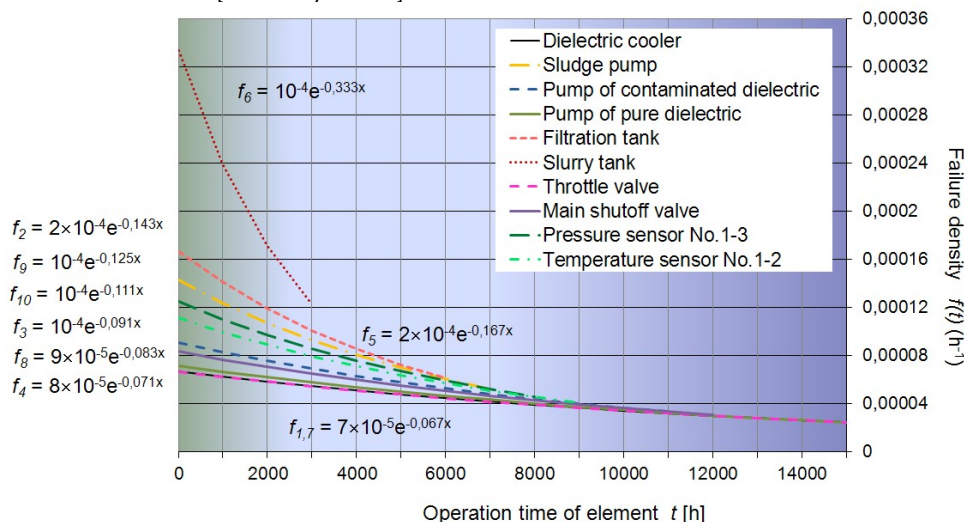


Figure 2. Exponential function of failures density $f(t)$ of particular elements of a given constructional unit for filtration and cooling dielectric fluid

By application of mentioned linear regression method a graphic formula was achieved. The graphic formula on the Fig. 3 presents dependence of failure rate on operation time of the constructional unit for filtration and cooling dielectric fluid of electroerosion unit machine AgieCut 270HSS. The diagram also presents histogram of failure occurrence in an absolute expression. Relative frequencies per time unit of operation show increasing number of failures however, this is due to the fact that the value came out from data about age profile of particular parts of the equipment.

Inserting of trend line made it possible to achieve parameters of linear regression curve a ; b ; and also parameters β and η of Weibull distribution.

Mathematical models for determination of selected reliability indicators of observed constructional unit of technical equipment AGIECUT 270HSS are following:

- when $a = 0.0001$ and $b = 2 \times 10^{-6}$ then for failure rate determined by linear regression following formula holds true:

$$\lambda = 0.0001 + 2 \cdot 10^{-6} t \quad (16)$$

- when for shape parameter it holds true $\beta = 2$, then formula (4) for calculation of failure rate based on Weibull distribution can be adjusted into this form:

$$\lambda = \frac{t}{\eta} \quad (17)$$

From this formula it can be observed that failure rate in this case is an effect variable in time t . Also depends on parameter of size which for given range reaches value $\eta = 9.61 \cdot 10^3 h$.

- when for shape parameter it holds true $\beta = 2$, then formula (7) for calculation of course failure density (Fig. 4) based on Weibull distribution can be adjusted into this form:

$$f(t) = \frac{t}{9.61 \cdot 10^3 h} \cdot e^{-\left[\frac{t}{9.61 \cdot 10^3 h}\right]^2} \quad (18)$$

Mathematical reliability model of comprising the selected reliability indicators of observed constructional unit for filtration and cooling dielectric fluid is following:

$$R(t) = e^{-\left(\frac{t}{9.61 \cdot 10^3 h}\right)^2} \quad (19)$$

On the basis of results of empirical calculation of reliability indicators of given technical equipment, it is possible to state that applying of linear regression for description of parameters of Weibull distribution was suitable. However, in detailed observation of results it is necessary to note that resulting parameters of Weibull distribution and consequential reliability indicators - failure probability density $f(t)$ and failure rate λ - do not reality accurately enough. This was proved also by correlation index IK^2 which value was $IK^2 = 0.7514$.

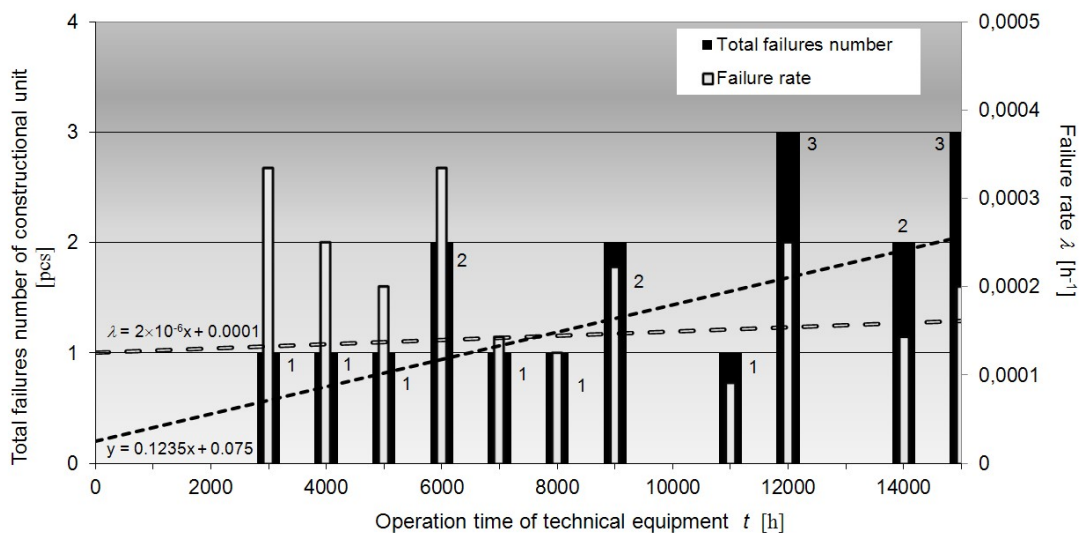


Figure 3. Dependence of total failures number and failure rate λ on operation time t of constructional unit for filtration and cooling dielectric fluid of electro-erosion machine AgieCut 270HSS

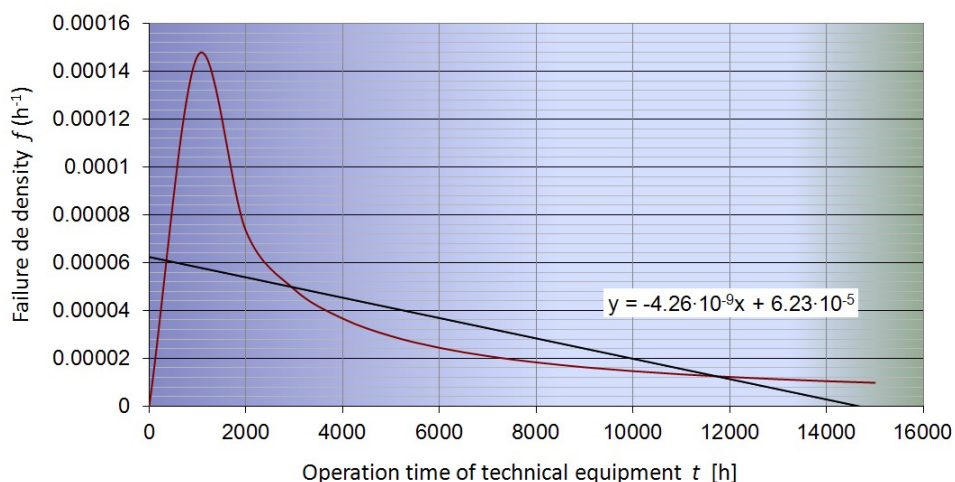


Figure 4. Function of failure density $f(t)$ of constructional unit for filtration and cooling dielectric fluid of electro-erosion machine AgieCut 270HSS

4 CONCLUSIONS

The paper describes in detail the procedure of creation of reliability model applied on constructional unit for filtration and cooling dielectric fluid of electroerosion machine AgieCut 270HSS. The aim of the paper was to determination of reliability model one of selected constructional unit of electro-erosion machine for cooling and distribution dielectric on the basis of empirical reliability principles. For applying of this access for determination reliability of given constructional unit, it was necessary to know operational data. It was required to know moments of failures emergence as well as characters of failures. On the basis of data recorded in service protocols, basic reliability parameters were calculated. Probability of failure-free operation $R(t)$, failure rate λ and failure density $f(t)$ were chosen as representative reliability indicators, because these indicators represent best the course of failures occurrence of technical devices in dependence on their operation time t . For creation of reliability model it was inevitable to assign information about a failure emergence moment for each individual failure of observed unit of technical equipment. In control of random parameter an exponential and Weibull distributions was applied. Author justify the option for exponential and Weibull distributions by the character of failures that occur in given constructional unit of technical equipment. The purpose of quantification of reliability level of given constructional unit of electro-erosion machine it was established an accurate mathematical model. Even though, the future behaviour of the technical equipment cannot be predicted with 100% precision, and it cannot be guaranteed at all. However, it is a great achievement, if we – on the basis of reliability analysis – can assess a certain trend of failure occurrence of the observed technical equipment in dependence on its operation time. This provides a space for further improvement of the reliability level of observed unit of technical equipment.

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CONTACTS:

Assoc. prof. Luboslav Straka, PhD.
Technical University of Kosice with a seat in Presov
Faculty of Manufacturing Technologies
Department of Manufacturing Processes Operation
Sturova 31, 080 01 Presov, Slovak Republic
tel.: +421 55 602 6346
e-mail: luboslav.straka@tuke.sk