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RELIABILITY ASSESSMENT BASED ON INFORMATION COLLECTED DURING OPERATION

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Abstract: The paper presents a practical way to effectively assess the reliability in an operational manner, highlighting some of the strengths and weaknesses of the used method, and also drawing some frame ideas on how this operation should be done.

DETERMINING THE RELIABILITY OF AN ELECTRICAL EQUIPMENT BASED ON THE OPERATION DATA

The behavior monitoring during operation is an issue which requires good theoretical skills as well as practical experience. A special attention should be paid for:

- selection of essential parameters for equipment monitoring at a certain time;
- setting up of environment and stress conditions considering also the definite situations for equipment (system) components during real operation.

In order to make assessments related to electrical equipment reliability level it is considered a number n = N of components extracted among the population searched.

After sample creation and the monitoring starting it is not allowed to perform any maintenance operations at equipment.

If monitoring is interrupted for maintenance activities or due to other organizing reasons (unforeseen) it shall be resumed as soon as possible.

In emergency cases, the monitoring program can be simulated through different tests:

- full tests under simulated conditions; techniques based on using the existing correlation between real stresses and the behavior of equipment to be monitored under the same operation conditions
- full tests on components; this procedure is convenient both technically and economically due to fact that they can be applied especially on components which have been noticed as representing the reason of frequent damages of equipment leading to a higher volume of information related to equipment which generate damages
- detailed tests on modules which represent the most efficient means of checking the constructive design methods and solutions.

Due to the fact that the inspection is not performed for all equipment of the same type but only for a part of them it is possible to occur errors in estimating the reliability of the searched equipment. Therefore, it is strictly necessary to interpret the results by estimating the reliability parameters and to guarantee the results having a certain degree of confidence.

During tests it is necessary to perform systematic recording used as the basis of the final decision related to tests and the information should include:

- time (tests starting, damages occurring time etc.)
- identifying the components replaced or restarted
- details on stress and environment conditions

Different methods of expressing reliability can be considered as estimators of the same real reliability, but unknown. By setting up some relations between estimations of the same reliability the initial design data might be better defined, such as the specifying of resistance at electrical / mechanical wear correlated with α significance level.

The different environment conditions which have to be supported by equipment during operation lead finally to damages occurring sometimes during the early lifetime. Therefore we can consider that the damage modes are classified as follows:

- general failure modes coming from system reliability defining,
- specific failure models.

1.	Premature operation
2.	Do not operate at foreseen time
3.	Do not stop at foreseen time
4.	Damaging during operation

The equipment reliability is set up based on the constructive solution adopted defined by the design itself. During the following stages (performance of prototype and of "zero" series, product certifying, manufacture) the equipment reliability is often lower then the provided at design stage

This remark considers several factors interfering the equipment assimilation cycle, such as:

- design models limits and inaccuracies,
- uncertainties in using data for previsional reliability computation,
- limits of real stress factors modeling at certifying tests carried on in laboratory.

The evolution of an electric equipment reliability level (according to the development stages) during assimilation cycle is presented below

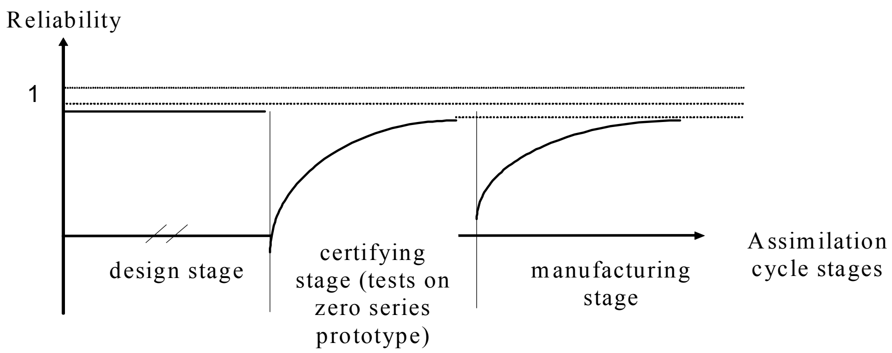

Fig.1 Equipment Reliability Cycle

SAMPLES, VOLUME "N"

During one equipment operation, it is gradually becoming warn and therefore losses its metrological qualities, its errors become higher and at a certain time exceeds the values admitted by its class. At this time, the equipment should be taken out of operation, repaired and checked. Unfortunately this time can not be determined; the good operation time of an equipment τ is a transient variable.

If we mark τ repartition function by:

$$P(\tau < t) = F(t), \quad (1)$$

the probability for the equipment to work at time t is

$$P(\tau > t) = 1 - F(t) = R(t) \tag{2}$$

R(t) is named the equipment reliability function expressed to the probability for it to fulfill the functions under prescribed conditions during a given period of time. Function R(t) is determined through experiments.

For this purpose N devices are tested at a time interval t_0. At the end of the period it is ascertained that n have been damaged. If N is large enough, then:

$$R(t_0) = \frac{n}{N} \tag{3}$$

By changing the tests duration there are obtained other points of the function which has the configuration:

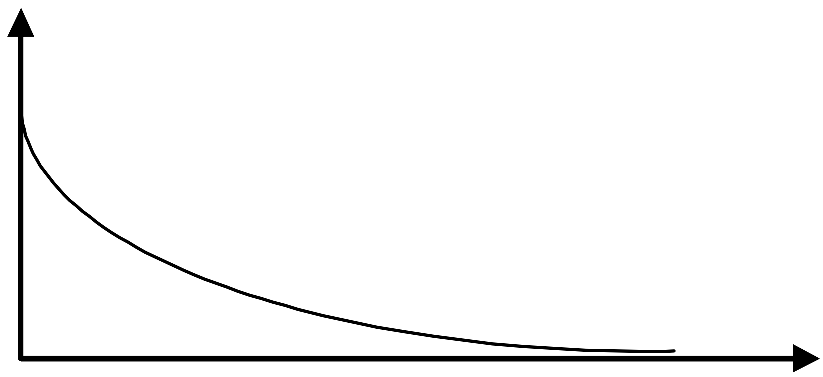

Fig.2 Reliability degree

Out of the reliability function it can be calculated the probability density of the good operation time, W(t):

$$W(t) = \frac{dF}{dt} = -\frac{dR(t)}{dt} \tag{4}$$

By means of this relation, the average of the good operation time, MTBF:

$$MTBF = \int_0^\infty tW(t)dt = -\int_0^\infty Rt^{'}(t)dt = \int_0^\infty R(t)dt \tag{5}$$

The minimum values admitted for these two parameters, $R_{min}(t)$ and $MTBF_{min}$ are determined by norms. It exists also the third planned parameter i. e. the damage rate.

As to define this parameter, it has to be calculated the probability conditioned that an equipment which operated during the interval (0, t) to operate correctly during the following interval (t, t_1), $P(t, t_1)/(0, t)$. Thus:

$$P(t,t_1)/(0,t) = \frac{P(0,t_1)}{P(0,t)} = \frac{R(t_1)}{R(t)} \tag{6}$$

Therefore, the damaging probability during interval (t, t_1) is:

$$Q(t,t_1) = 1 - P(t,t_1)/(0,t) = \frac{R(t) - R(t_1)}{R(t)} \tag{7}$$

If $t_1 = t + \Delta t$, then by the development in series and retaining the first terms, it is obtained:

$$Q(t,t_1) = \frac{R(t) - R(t+\Delta t)}{R(t)} = -\frac{R'(t)}{R(t)}\Delta t \tag{8}$$

Marking:

$$\lambda(t) = -\frac{R'(t)}{R(t)} \quad ? \quad Q(t,t_1) = \lambda(t)\Delta t \tag{9}$$

Therefore, λ(t) is the damaging probability density at time t, conditioned by the fact that the component operated without damages up to that moment. λ(t) is named damaging intensity rate and represents the third reliability planed parameter.

As to determine by experiment the damaging rate the following relation is used:

$$\lambda(t) = \frac{\frac{1}{\Delta t}\left[\frac{n(t)}{N} - \frac{n(t+\Delta t)}{N}\right]}{\frac{n(t)}{N}} = -\frac{\Delta n}{\Delta t n(t)} \tag{10}$$

Therefore, λ(t) is the number of damages occurred within the time unit as ration to the number of components which have not been damaged up to the given moment. If it is known the rate of damages, the reliability function can be quickly calculated:

$$R(t) = e^{-\int_0^t \lambda(t)dt} \tag{11}$$

If: λ = constant:

$$R(t) = e^{-\lambda t} \tag{12}$$

It is obtained an exponential law for the reliability function. In this cases, the average of the good operation time becomes:

$$MTBF = \int_0^\infty R(t)dt = \int_0^\infty e^{-\lambda t}dt = \frac{1}{\lambda} \tag{13}$$

The current norms admit the exponential law for the reliability function. In fact, based on experimental data, λ(t) has the shape presented in the figure below, where three areas can be seen. Area I corresponds to the so-called youth of products. Some are damaged rapidly soon after commissioning due to hidden manufacture defects which could not be noticed at inspection. The initial part of the area I can have different shapes. Area II (maturity) when the damages rate is practically constant and the exponential law can be applied. Area III (aging and wearing) is following, when the equipment are damaged to a greater and greater extent.

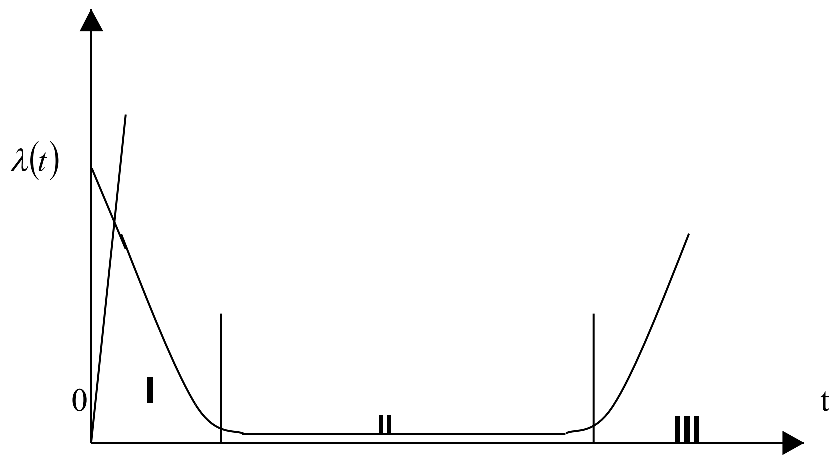

Fig.3 Damages rate

In some cases, the reliability function is better approximated by Weibull law, with two parameters $R(t) = e^{-\lambda t^{\alpha}}$ where the damages rate is $\lambda(t) = \alpha\lambda t^{\alpha - 1}$

DATA COLLECTING THROUGH PRODUCTS MONITORING DURING OPERATION

The statistical techniques for reliability assessment are performed based on certain plans previously setup. Thus, assessments can be performed based on the results obtained both through behavior monitoring during operation and through laboratory tests.

Based on the data collected there can be estimated as points and as confidence intervals the main reliability indices for equipment and/or systems. The results obtained after equipment behavior monitoring during operation will be analyzed and interpreted considering the following aspects:

- statistic methods (sample size, forecast, assessment etc.);
- analysis of equipment sample;
- aspects related to human factor during monitoring process;
- results obtained under the same operating conditions.

It is necessary to specify that for applying statistical methods for estimating the reliability indices, we basically have to know the good operation time distribution law. For equipment behavior monitoring during operation the exponential law is used as reliability theoretical law. Starting from the purpose of tests – to initiate actions for reliability increasing – the results of tests should be synthesized as measuring (testing) ratio. This ration should be full and accurate so that to be used for decisions related to the tested equipment reliability.

The main components of the report are:

- data recording and operation sheet including equipment identifying and chronological recording of remarks and interventions;
- damaging report including: information supplied by the operator, symptoms of damaging, conclusion of damage reason, corrective measures recommended, repairs performed, replaced components identifying;
- list of damages including: general information, chronological list of relevant damages, information related to repairs, damage reason, corrective measures and measures for equipment improvement;
- report synthesis, including final conclusions and measures proposed.

Considering only the aspects related to accidental damages during equipment normal operation we can estimate:

- reliability indices estimated values are determined by statistical processing of data obtained during electrical equipment operation;
- a special aspect of electrical equipment monitoring during operation is to limit and create the monitored sample

The date obtained further to operation and possible deviations of technical conditions through laboratory statistical processing will finally lead to operation reliability setting up.

One condition is to limit the lot of equipment as to fulfill the homogeneity conditions so that the equipment monitored to have the same manufacturing characteristics and to be monitored in the same or similar conditions.

SOME CONCLUSIONS RELATED TO THE WAY OF MONITORING BEHAVIOR UNDER OPERATION:

a) basically, the program for equipment behavior monitoring during operation should be applied in an intelligent manner considering permanent revision and periodic adaptation as to comply with the elements of other programs and the new aspects occurred in the technical fields related to quality and reliability assurance;
b) it is important to perform a full and adequate recording of data related to the evolution of operation and performance quality and of damages occurred during the entire interval monitored;
c) it should be performed a thorough inspection program performed by qualified and trained personnel authorized to check and monitor the equipment considering also strict recording of its behavior during operation;
d) the technical functions for quality and reliability control are interdependent and they are influencing each other.

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