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AGING EQUIPMENT PREDICTION USING THE WEAR PROCESS

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***Abstract* – An element fails as soon as the applied stress is at least as much as the strength of the element. Stress and strength are time-varying in many real-life systems but typical statistical models for stress-strength systems are static. In this paper the stress and strength processes are dynamically modelled as quasi-stationary process. Also because the stress and strength process depend on many number of parameters, hence the time to failure will be modelled like a random variable.**

Keywords: *stress and strength distribution quasi-stationary process, lifetime.*

1. INTRODUCTION

The reliability of an element is the probability that the element will perform its intended function adequately for a specified interval of time, under stated environmental conditions. The fault concept of element is directly connected to the reliability concept, especially by the concept that the element must accomplish the functions for which it was designed and realized.

Each element can be characterized by a determined parameter, which serve as measure of its performance and which can be a parameter or a vector with more components. In function of the determined parameter which characterizes the element running, the defection can be given after the way in which the growth and the reduction of the determined parameter surpass or decrease under the limit values.

The best way to select a life time distribution model would be to describe the physical phenomena producing the failure and then to use these phenomena as a logical basis for derivation of the distribution model. In fact, we don't model the so-called defection, but the behaviour in the running of the studied equipment, from the point of view of the analyzed parameters evolution. These aspects present in essence the stress-strength models development in other papers [1]. So, in this paper, these concepts will be modelled like random variables. The fault model must consider the manner and the speed of variation in time of stress and strength variables. The actions of successive stresses are generally unforeseeable, the failure can appear in any moment, and in addition the degradation of strength has the various speeds and trends. The reliability definition includes the time factor importance. The essence is that the strength vector components are not increasing in lifetime or in time intervals between maintenance operations. The stress laws are given time depending shapes. Hence, the time to failure will be modelled like a random variable, for that, we will estimate the probability distribution function.

2. ONE-DIMENSIONAL STRESS STRENGTH INTERFERENCE PROCESS

The problem of interference about the stress-strength model arises in many areas of reliability, the element performs its intended task if the strength is greater thant the stress. Even when identically elements are subjected to the same fluctuating stress, they fail at the different cycles because of different proprieties of materials. The fault of a component or a system may be defined like the cessation of their function for what it was designed and conceived. The component works for how long time the stress is less than strength.

In order to compute the reliability we have to define the stress, strength and random process concepts. The stress concept is used to indicate any action that tends to induce the element failure. The stress can be an extern stress, caused by the environmental factors or by interaction with other elements or systems, respectively, the internal stress caused by itself construction and function. The strength concept is used to indicate any actions or element properties that resist to the element failure. The elements are characterized by strength, that is a measure of element quality, and, that generally, is a vector of random variables for varied element stress.

This is uncertainly about the parameters and distribution of stress and the strength random variables at any instant of time, and also about the behaviour of the random variables with time.

The random process represents totality observation, in time, about a random variable, and here we will use to indicate the behaviour of the stress and strength variables in time. Also, a process supposes the fixed behaviour of the variable in time or, in other words, the variables varies in time in a known manner. These suppositions are defined using the non-, quasi- and stationary process concepts, and that presents the statistically dependence behaviour of variables in time. Generally, the behaviour of the variable in time is characterized:

- the stress vector varies in time in a stationary manner. This means that the random variable don't change in time its parameters;
- generally, the strength vectors varies in a negative direction (deterioration), this means that is known how the strength decreases in time, because of some irreversible process of wear or of aging. The strength vector is assumed to vary in a random manner, but, in case of the successive dependent values for a certain time interval, we can specify that the strength vector varies in a predetermined (quasi-stationary) manner.

For irreversible process of wear or of aging are typical the statistical dependence between successive values of strength process. Each element has a proper wear curve, the same class of element has the similar trends or parameters wear curve. So, the wear process will be modelled using that process which varies in a predetermined manner, precisely the quasi-process.

Because of a large variety of working conditions, it is not available a large volume of information about evolution in time of strength process. Many times, in working process, the parameters of element strength have estimated only one or two times, thus, from these few information, we will make assumption about the real wear process. It is necessary, in the time of wear process development, to extrapolate and interpolate the available strength variable values. For that it is necessary a hypothesis about the trends of wear curves. The evolution in time of the strength vector components, as random variables, has already known shapes like in figure 1.

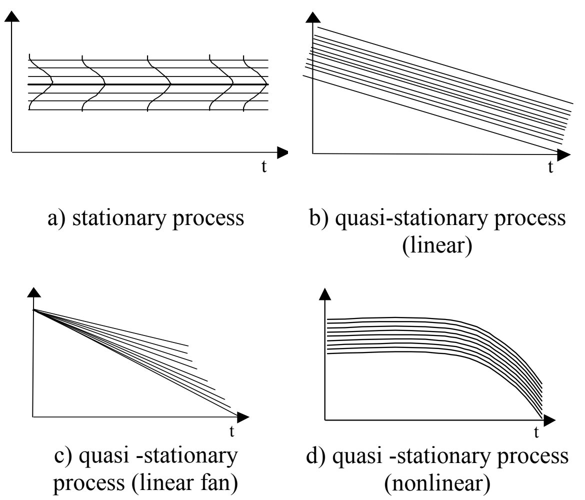

Figure 1: The evolution of the strength process

In practical applications we will use most simple quasi-stationary process for modelling the wear process, namely the linear uniform process, the polar process and the linear polar process, the first two processes being particular cases for the linear polar process. Generally, the strength variable is a normally distributed for which mean and standard deviation varied with time in following manner:

$$\begin{cases} M[C(t)] = M[C_0] - M[\Delta C \cdot t] = m_0 - \Delta m \cdot t \\ D[C(t)] = D[C_0] + D[\Delta C \cdot t] = \sigma_0^2 + \Delta\sigma^2 \cdot t^2 \end{cases} \quad (1)$$

The characteristic parameters of the wear process can be estimated if we know the statistical dates of wear process values at least two moments in time (t_1, t_2).

For the wear process, it is not rational to estimate the general relationship, because these are very complex and in addition in practical analysis of the wear process it is possible to neglect many correlation links, simplifying the relationship for each case.

3. THE ESTIMATION OF THE FAILURE DENSITY FUNCTION

For structural components working reliability estimation, stress strength interference model is one of the most commonly used methods. The development of the element failure distribution can be approached from the evolution in time of the failure model, more exactly, the evolution of the reliability in time, for each kind of stress.

Knowing that the stress process and, also that the wear process is a quasi-stationary (linear) process, we will establish the reliability evolution and after that, differentiating, we will obtain the failure distribution. The relation between the failure distribution and evolution in time of the stress-strength process is illustrated in figure 2.

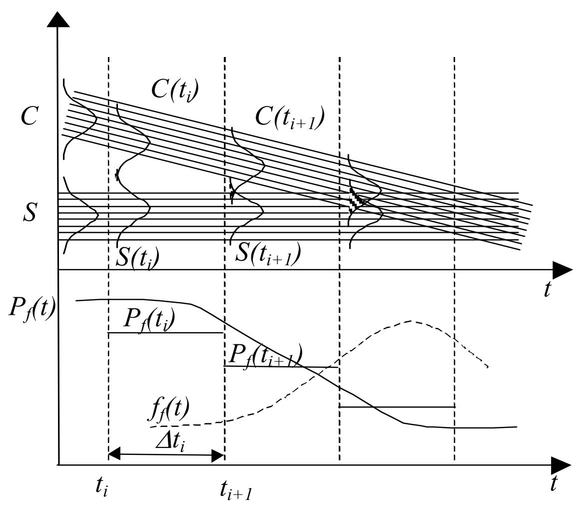

Figure 2: The relationship between the reliability indices and stress-strength process.

When applied stress demand, *S*, and strength capability, *C*, defined by probability distribution, failure occurs when the tails of the two distributions overlap. The tail-overlap area suggests the probability that a weak resistive material will encounter an excessively applied stress to cause failure. The probability P_{di} is the probability that the element will fail in time t_i, corresponding to hatch area to moment t_i. The growth of these area in period (t_i, t_{i+1}) is proportional to the element failure probability in that period.

The failure distribution computation can be realized for each period $\Delta t_i = t_{i+1} - t_i$ calculating the mean value of failure distribution for that period, dividing the growth of failure probability to the duration $\Delta t_i = t_{i+1} - t_i$:

$$f(t_i)_{med} = \frac{P_d(t_{i+1}) - P_d(t_i)}{t_{i+1} - t_i} \quad (2)$$

With these values we will draw a continuous curve depending on time t_i.

The failure is defined to have occurred when the actual stress exceeds the actual strength for the first time. The failure probability arises from the stress-strength interference, using the following relationship:

$$P_d = 1 - \int_{-\infty}^{\infty} F_S(C) f_C(C) dC = \int_{-\infty}^{\infty} F_C(S) f_S(S) dS \quad (3)$$

These analytic and numeric models were developed, examined and presented by authors in others paper [2].

4. THE RELIABILITY COMPUTATIONS FOR A CIRCUIT BREAKER

The circuit breaker equipment has the role to connect and, especially, to break the nominal and short-circuit current. The most important role is the protection network, moment in which the switching equipment is stressed by short-circuit stress. The problem is to determine the time to failure until short-circuit current stress exceeds the actual capacity rated short-circuit-breaking current for the first time, taking into account the wear process.

The models developed in the paper will be applied in the case of a real, known network following the way in which short-circuit distribution from the network influence the reliability of the switching equipment. We will analyze a radial line supplied from a source G, using a transformer T, such is presented in figure 3.

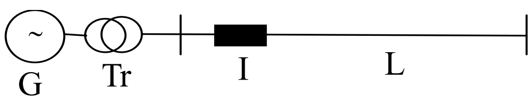

Figure 3: The radial line supply.

The equivalent short-circuit scheme is presented in figure 4:

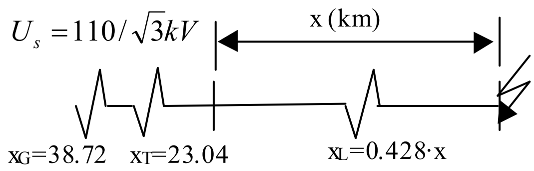

Figure 4: The short-circuit scheme.

The parameters of the equipments are:

G	Tr	I	L
S_{ng}=62.5MVA	S_{nt}=63 MVA	IUP 110kV	x_0=0.428
U_{ng}=10 kV	$U_{jt/it}$=10/110kV	I_n=630 A;	Ω/Km
cos φ=0.8	Y_ND	S_{rup}=1900 MVA	L=100 Km
x_d"=0.2	u_{sc}=12%		
		I_{lt}=7 kA,	
		t_{lt}=10 s	
		I_{ed}= 33 kA	

We will estimate the stress distributions given by the current of short-circuit of the circuit breaker equipment, and also the distribution of the strength (normally distributed), and the probability of circuit breaker equipment to break the short circuit current.

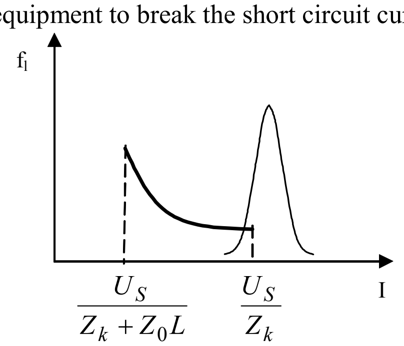

Figure 5: The distributions interference.

We will analyze also the parameter evolution, especially the strength, which evolve in negative sense (deterioration), because of some irreversible process of wear or of aging, till, reaching a critic value equal with the actual stress, lead to the equipment fault.

Using a linear process for wear process with following parameters:

- initial value of the strength component: mean $m_0 = I_{rup}$ and standard deviation $\sigma_0 \approx 0$;
- the variable, which describes the wear speed: Δm=1A/[T] şi $\Delta\sigma$=1 A/[T].

In the following figures are presented the evolution in time of the failure probability and the failure distribution, depending on various wear speeds.

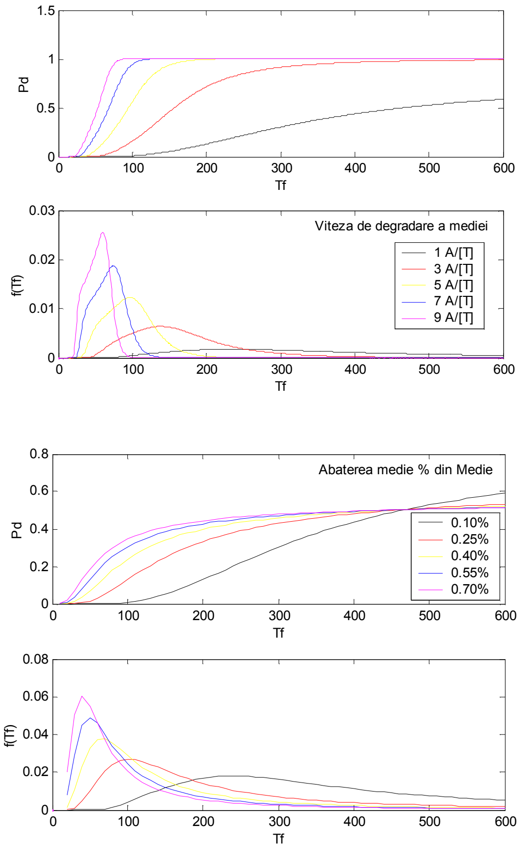

Figure 6: The probability and the distribution functions.

Comparing the failure rate of the distributions with the real data of the circuit breakers, from PE013/94, (λ=0.033 failure/short-circuit), we can estimate the degree of wear process, described by last wear speed process.

4. CONCLUSIONS

This paper develops models for reliability distribution, which consider the continuous application of stress and also the changes of the distribution of strength with time. The simulation models was developed in order to study the failure phenomena for a circuit breaker equipment subjected to short-circuit current stress and strength degradation due to wear or the aging, with various wear speeds.

References

[1] C. Nemeş, D. Ivas, Fl. Munteanu, *Estimarea defecțiunilor folosind modelul static solicitare – rezistență*. SIELMEN Chişinău 2001;

[2] Ivas D, Munteanu F., Nemeş C. *Ingineria fiabilității sistemelor complexe*. Ed. Perfect Bucureşti 2001.

[3] C. Nemes, D. Ivas, F. Munteanu *Probabilistic approach for thermal and electro-dynamic stresses distribution functions* Second Regional Conference on Electricity Distribution, 17-20. October 2006. Zlatibor, Serbia. ISBN 86-83171-13-2. Pg.11.