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Reliability functions for elements of the system in failure state

SUMMARY

A method is presented of determination of reliability function values for elements of the complex engineering system which operates at unserviceability conditions of some of its elements, i.e. in a failure state. The method is based upon information about element's reliability in the normal state of operation of the system as well as in the system overload state resulting from unserviceability of other elements.

INTRODUCTION

The outfit machines of the sea-going ships form the systems which cooperate with or take over functions from other machines or elements. It results from the necessity to assure safety of the ship or her vital subsystems. Such structures, being parallel on the assumption, are required by the rules of the classification societies.

The anchoring systems (usually two anchors are required for every ship), or diving bell hoisting systems (where guiding cables are used to hoist the bell in failure state) could exemplify such structures. Also, the parallel plate rudder systems or taking-over the role of the systems by the stern/bow thrusters or even by the twin-screw main propulsion plant e.g. that of CP propellers, may be so considered. Such systems can be built in accordance with different principles, however in many cases it appears that as soon as one or several elements become unserviceable the remaining elements will start operating in an overload state. The overload is a source of worthening reliability of the elements operating in the state of not quite full serviceability of the system [6] which can lead to increasing probability of loss of safety. For instance the multi-cable anchoring system of a drilling platform, in the case of breaking of one or more cables, operates in the overload state of the remaining cables in comparison to their nominal loads. The state will last until the failed elements are replaced or repaired. The failure effects in sudden change of the failure intensity function $\lambda(q)$ and, in consequence, sudden change of the slope of the tangent line to the reliability curve $R(q)$ at $q = q_a$, where q_a is the number of the cycle in which the failure of an element randomly occurred.

In the below presented examples the following approximate form of the reliability function is used :

$$R(q)=e^{K\left(\frac{q}{q_z}\right)^b}-c \qquad K=ln[(R)_{q_z}] \tag{1}$$

and of the failure intensity function :

$$\lambda(q)=\frac{R'(q)}{R(q)}=-K\frac{b}{q_z}\left(\frac{q}{q_z}\right)^{b-1} \tag{2}$$

where :

- q – operation time coordinate measured e.g. in diurnal periods
- q_z – total number of periods, determining operation time period
- $(R)_{q_z}$ – final value of reliability function
- b – curve shape factor
- c – deducted constant value.

Many other approximate relationships based on the assumed random distributions are available [3]. Values of the parameters

$$(R)_{q_z},\ b \text{ and } c$$

result from the computational or experimental analyses which lead to description of the element reliability function [4]. Therefore the character of the phenomena which cause the destruction processes to be described is decisive. For instance ship motion characteristics [1,5,8] are important in analyzing the material fatigue processes [7] occurring in the deck machine elements of sea-going ships.

Knowledge of such processes makes it possible to describe the element reliability function of the system at normal operation conditions as well as in an overload state. These are the initial data to be applied in the below presented method.

DESCRIPTION OF THE FAILURE-STATE RELIABILITY FUNCTION

The principle of determining the system reliability function in the failure state is presented in Fig.1. Let the function $R_N(q)$ which describes element reliability in the normal (rated) state is assumed. Also, the function $R_0(q)$ is given which describes the reliability in the load state equivalent to an overload state lasting for the entire period of operation. The failure intensity functions $\lambda_N(q)$ for the normal state and $\lambda_0(q)$ for the overload during the entire operation period correspond to the reliability functions in question.

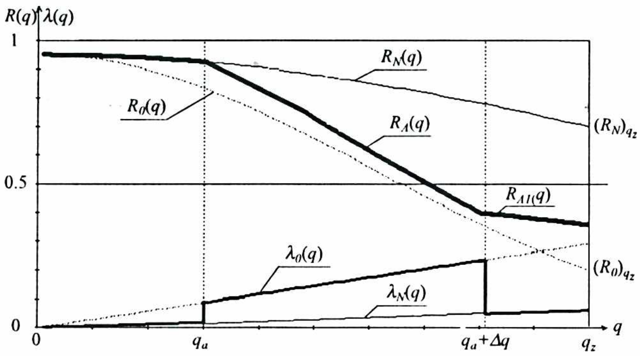

Fig. 1. The assumed principle of determination of the system reliability function for the failure state

Assumed parameter values : b = 2 c = 0.05
For normal state $(R_N)_{q_z}$ = 0.750
For failure state $(R_0)_{q_z}$ = 0.250

If during the considered period a failure occurs of any element which cooperates, within the system, with the element of the characteristics presented in Fig.1, then the characteristics will be changed. Hence the influence is considered of the failures of other elements of the system on the reliability characteristics of the still operating elements. In this way the operation of the elements during the failure state of the system is defined.

Let's assume in a simplified way that at the time q_a the failure intensity function value of an overloaded element suddenly increases from $(\lambda_N)_{q_a}$ to $(\lambda_0)_{q_a}$. After replacement of the failed element, effected after Δq load periods, the function comes back to the normal-state function through sudden change of its value from $(\lambda_0)_{q_a+\Delta q}$ to $(\lambda_N)_{q_a+\Delta q}$.

During operation of the failed system i.e. in the period of

$$q_a \leq q \leq q_a + \Delta q$$

the element reliability function can be described by the following relationship useful for computerized calculations :

$$R_A(q) = R_A(q-1) + R'_A(q)\Delta q \qquad \Delta q = 1 \tag{3}$$

and from the definition :

$$R'_A(q) = -\lambda_0(q) R_A(q) \tag{4}$$

hence :

$$R_A(q) = \frac{R_A(q-1)}{1+\lambda_0(q)} \tag{5}$$

and the continuity condition of the reliability function in the time period $q = q_a$ should be assumed as follows :

$$q = q+1 \;\Rightarrow\; R_A(q-1) = (R_N)_{q_a} \tag{6}$$

and the initial condition :

$$q = 1 \;\Rightarrow\; R_A(q-1) = (R_N)_1 \tag{7}$$

After coming back of the system to normal operation i.e. at

$$q > q_a + \Delta q$$

the after-failure reliability function can be described by the following relationship :

$$R_{A1}(q) = R_A(q-1) + R'_{A1}(q)\Delta q \qquad \Delta q = 1 \tag{8}$$

and since :

$$R'_{A1}(q) = -\lambda_N(q) R_{A1}(q) \tag{9}$$

then :

$$R_{A1}(q) = \frac{R_{A1}(q-1)}{1+\lambda_N(q)} \tag{10}$$

and the continuity condition at $q = q_a + \Delta q$ can be expressed by :

$$q = q_a + \Delta q + 1 \;\Rightarrow\; R_{A1}(q-1) = \frac{R_A(q+\Delta q)}{1+\lambda_0(q)} \tag{11}$$

INFLUENCE OF ELEMENT REPLACEMENT AND MULTIFOLD FAILURES

It can happen that a failed element of the system is not replaced and overloading lasts very long, even to the end of operation of the system. Then it should be assumed that :

$$\Delta q = q_z - q_a \tag{12}$$

In this case the reliability function of the failed element obtains the form presented in Fig.2. The failure intensity function $\lambda(q)$ increases at $q = q_a$ by sudden changing to a value of $(\lambda_0)_{q_a}$ and follows (is identical with) this function up to the end of the considered operation period of the system.

The relevant reliability function has two segments : the first one valid up to the failure instant, identical with the normal-state function, and the second one valid after that time, described by the equation (5).

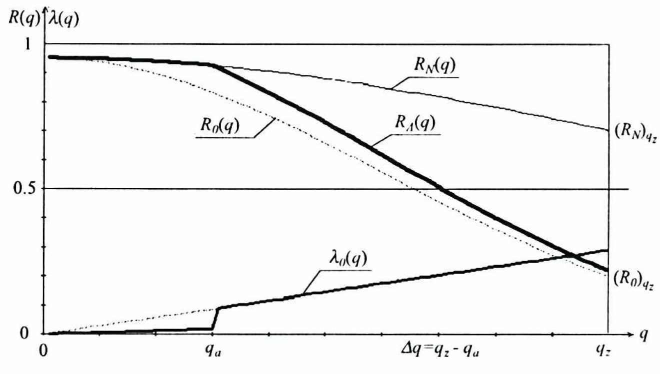

Fig.2. The failure-state reliability function of the system at neglected replacement of an element

Assumed parameter values : b = 2 c = 0.05
For normal state $(R_N)_{q_z}$ = 0.750
For failure state $(R_0)_{q_z}$ = 0.250

In the case of short-lasting overload, e.g. when it happens during one period only (immediate replacement of the failed element), the course of the failure-state reliability function is such as that shown in Fig.3.

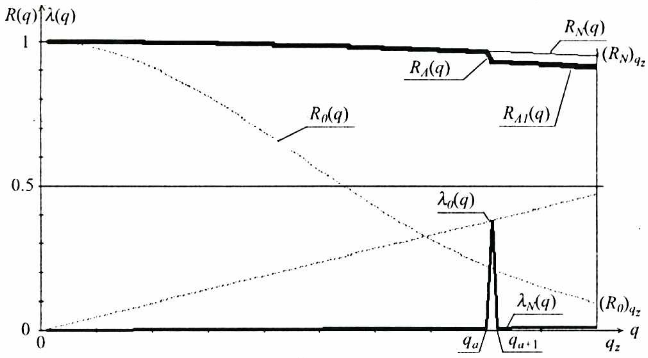

Fig.3. The reliability function at short-lasting overload

Assumed parameter values : $b = 2$ $c = 0$
For normal state $(R_N)_{q_z} = 0.95$
For failure state $(R_0)_{q_z} = 0.095$

The input data assumed for this example provide the easily noticeable effect of reliability drop in spite of the short duration time of the failure state. It was achieved by assuming the high overload value which the reliability function $R_0(q)$ is equivalent to. After overloading the reliability function value decreases to that determined by (5) and further the function obtains values in accordance with (10).

In practice the cases can happen of more than one failure triggering step-by-step growing overload of the unfailed elements. If two subsequent failures are assumed: the first within the period q_a and the second within the period q_{a1}, and the duration time of each overload is the same and equal to Δq then the reliability function will be of the character shown in Fig.4.

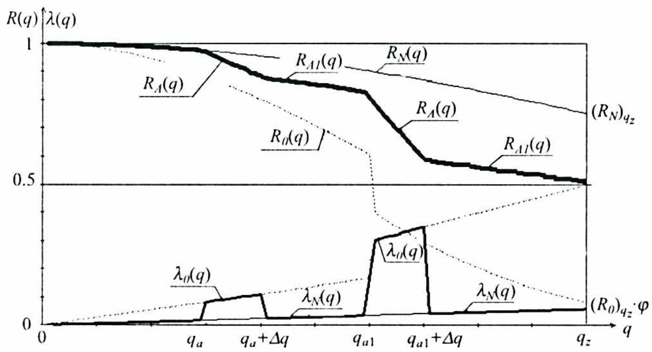

Fig.4. The reliability function at two subsequent overloads

Assumed parameter values : $b = 2$ $c = 0$
For normal state $(R_N)_{q_z} = 0.750$
For failure state $(R_0)_{q_z} = 0.250$

The function is now composed of five segments, namely :

- the initial segment in accordance with the normal-state function
- the first-overload-state segment described by (5)
- the after-first-replacement-state segment described by (10)
- the second-overload-state segment described by (5)
- the after-second-replacement-state segment described by (10).

The sudden change of the failure intensity function $\lambda_0(q)$ was obtained in such a way that the final value $(R_0)_{q_z}$ of the reliability function in the overload state in the period q_{a1} was multiplied by a value of the reduction factor φ (assumed 0.333 in this example) which should result from the overload consequence analysis.

Results of two subsequent overloads are also shown in Fig.5. However they relate to the situation of replacement negligence which, as it results from Fig.4, can lead to important worsening the reliability function. The function has not the segments described by (10) and the jump of the failure intensity function was achieved by the afore applied reduction factor φ of the same value.

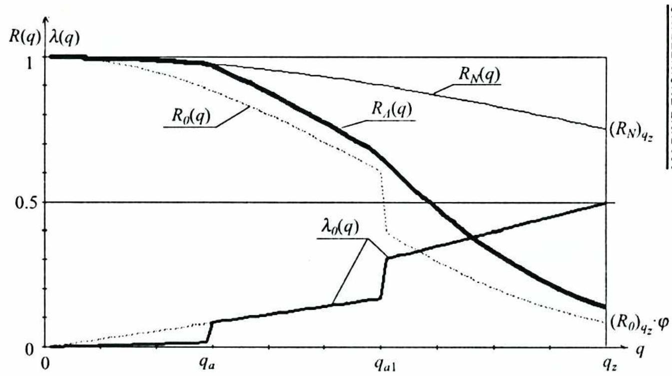

Fig.5. The reliability function at two subsequent overloads and neglected replacements

Assumed parameter values : $b = 2$ $c = 0$
For normal state $(R_N)_{q_z} = 0.750$
For failure state $(R_0)_{q_z} = 0.250$

All figures presented in this section are the computer screen copies showing the calculation results obtained with the use of APNIEZA1 software. It is applied to calculate examples of the reliability function based on the approximate relationships (1) and (2).

FINAL REMARKS

The presented method of determination of the reliability functions of the elements during operation of the system in the failure state (not quite fully serviceable) can help to improve adequacy of the analyses in confrontation with real course of phenomena. These are the analyses of safety and reliability of the complex systems, carried out by means of the software based on an analytical approach to occurrence of detrimental random events during operation of such systems [4], [9]. The method makes it possible to assume values of the reliability function adequately to current state of the system in question. The values determined with accounting for random overloads of some elements in result of failures of other elements, are lower at least temporarily. It leads to more pessimistic predictions and thus to more realistic (accurate) analysis results.

NOMENCLATURE

- b - curve shape factor
- c - deduced constant value
- e - Napierian base (e = 2.718)
- q - operation time coordinate measured e.g. in diurnal periods
- q_a - number of the period
- q_{a1} - number of the second failure period
- q_z - total number of periods, determining operation time period
- R - reliability
- R_A - reliability for the failure state
- R_{A1} - reliability for the state after repair
- R_N - reliability for the normal state
- $(R_N)_1$ - value of the function $R_N(q)$ in the first period
- R_0 - reliablity for the overload state
- R' - derivative of the reliablity function R(q)
- $(R)_{qz}$ - final value of the reliability function
- λ - failure intensity
- λ_N - failure intensity for the normal state
- λ_0 - failure intensity for the overload state
- φ - reduction factor

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