447. Assessment of damage risk function of structural components under vibrations

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(Received 25 January 2007; accepted 10 March 2007)

Abstract. In the analysis of reliability of construction element in the case of aging under vibrations, evaluation of risk function is of great importance. In practice, the applied constant risk function intensity is approximate. The intensity function must be evaluated timely. However, this effort requires numerous experimental data. This article considers a simplified approach for solution of the aforementioned problem. Provided comparison of experimental and obtained theoretical results confirm the validity of the presented approach.

Keywords: reliability, risk function models, risk function intensity.

1. Introduction

Vibrations may induce aging mechanisms in pipelines, pumps, motors or any other structures, which have some vibration environment.

Functions of construction element failure are usually determined by means of experimental research. Therefore theoretical analyses in the evaluation of risk functions simplify this effort.

Many studies have been devoted to evaluation of objects reliability [1-4]. However, research of risk of failure of construction component due to aging under vibrations is scarce [5,6]. Evaluation of this effort is described subsequently failed components, due to aging under vibrations, are replaced with new components. Risk function due to aging or failure frequency is on increasing progress. Therefore, the objective is to analyze risk function at any time interval t .

2. Basic Assumptions

Risk functions intensity $\lambda(t)$ is considered positive when $t \geq 0$ in a short time interval (period) (t, $t+\Delta t$). When $\Delta t \to 0$ failure analyses become independent, then failure count in time interval 0 and t are described as coincidental variable $\wedge(t)$. An assumption is made that component replacement after each failure is rapidly initiated and replacement time is of no importance.

Function λ is Poisson's process intensity function, and $\wedge$ is increasing risk function. If λ is not interrupted during time interval t, then λ is associated with an increasing directive function $F(t)$ dependant from first failure time and on frequency function $f(t)$.

Therefore [5]:

$$\lambda(t) = f(t)[1 - F(t)] \tag{1}$$

Resulting in:

$$1 - F(t) = exp[-\wedge(t)] \tag{2}$$

When $F(t) \to 1$ and $t \to \infty$ following lim $\wedge(t) = \infty \quad t \to \infty$
In this case, an indescribable effect is encountered. If $\lambda(t)$ is positive, then it is considered that the first failure time has an exponential directive. Therefore, simplified effort is attained. However, $\lambda(t)$ may increase in time t.

Resulting in:

$$\lambda(t) = \lambda_o h(t, \beta) \tag{3}$$

where λ_o – positive, and $h(t, \beta)$ determines $\lambda(t)$.

If all components have the same functions h, they have the same β value. If it is possible to assume that all components have the same λ_o value. This is frequently used in practice, since determination of β value is fairly complicated. To consider β value to be positive as λ_o is incorrect.

3. Risk Function Models

The following are risk function models: linear, exponential and Weibull [6]. Linear model:

$$\lambda(t) = \lambda_o(1 + \beta t) \tag{4}$$

Exponential model:

$$\lambda(t) = \lambda_o\, exp(\beta t) \tag{5}$$

Weibull model due to numerous additional parameter requirements, is seldom used. Weibull model has a more appropriate usage when data is available in abundance.
Expressions (4) and (5) suggest the need to have starting risk function intensity λ_o and failure intensity $\lambda(t)$ variable form parameter β. However, determination of β requires significant amount of experimental data.

It is known that failure intensity $\lambda(t)$ and function $f(t)$ are considered independent [6]:

$$\lambda(t) = \frac{f(t)}{1 - \int_o^t f(x)dx} \tag{6}$$

The analyses – evaluation (6) of this equation does not provide accurate results [7]. The best results would be acquired by approximating red $\lambda(t)$ function as presented in model in Fig.1.

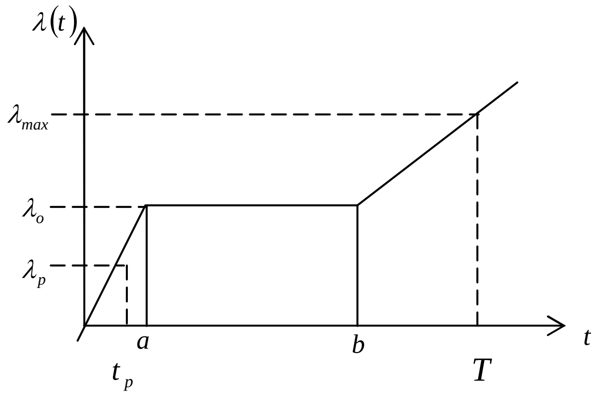

Fig. 1. Simplified failure intensively model

In the interval $0 < t < a$ function may be described as in the parameters of Weibull when $m = 2$ and $\lambda(t) = 2t_p - 1t$. In this manner mode is presented by three parameters: primary failure intensity λ_o, exploitation period b, after this effort beginning of failure intensity commencement characterized intensity λ_1.

Assuming intensity model possible presentation:

$$\lambda(t) = \begin{cases} \lambda_o, & \text{when } t = a; \\ \lambda_1, & \text{when } t = b; \\ \lambda_1 + \lambda_1 \dfrac{t-b}{t}, & \text{when } t > b \end{cases} \tag{7}$$

here λ_1 – failure intensity, when $t = b$.

Assuming exponential model:

$$\lambda(t) = \begin{cases} \lambda_o, & \text{when } t = a; \\ \lambda_1, & \text{when } t = b; \\ \lambda_1 \exp \dfrac{t-b}{b}, & \text{when } t > b \end{cases} \tag{8}$$

4. Presentation of model acceptance approval

The problem is in determining the location of the equipment and the associated vibration spectrum. For accelerometers, vibration is an input to the instrument. The ranges of frequency and the amplitude of such vibrations can be sizeable. Normal plant vibration of this kind is considerably different from vibration due to a seismic events, which is not an aging problem but a design event problem.

Analyzing atomic electrical construction components unity energetic norms NUREG/CR – 5378 [8] in support presentation of risk function intensity parameter β of variable time t effort. This effort is presented in table 1 [8].

Table1. Risk function intensity parameter β in time t

t, h	β, 1/h	
	Linear model	Exponential model
$2 * 10^4$	$1,2 * 10^{-5}$	$1,4 * 10^{-5}$
$4 * 10^4$	$1,9 * 10^{-5}$	$1,8 * 10^{-5}$
$6 * 10^4$	$2,6 * 10^{-5}$	$2,5 * 10^{-5}$
$8 * 10^4$	$3,1 * 10^{-5}$	$3,0 * 10^{-5}$
$1 * 10^5$	$3,4 * 10^{-5}$	$3,4 * 10^{-5}$
$1,2 * 10^5$	$3,6 * 10^{-6}$	$3,5 * 10^{-5}$
Average	$2,6 * 10^{-5}$	$2,6 * 10^{-5}$

Therefore average β effort is the same in both models as $\beta = 2,6 * 10^{-5}$ 1/h.

Basing on this analyses of risk function intensity may be presented λ, then $\lambda_o = 2,0 * 10^{-5}$ 1/h [8].

Calculation results are presented in table 2.

Table 2. Parameter $\lambda(t)$ changes in time

t, h	$\lambda(t)$, 1/h	
	Linear model	Exponential model
$2 * 10^4$	$3,04 * 10^{-5}$	$3,36 * 10^{-5}$
$4 * 10^4$	$4,08 * 10^{-5}$	$5,6 * 10^{-5}$
$6 * 10^4$	$5,12 * 10^{-5}$	$9,4 * 10^{-5}$
$8 * 10^4$	$6,16 * 10^{-5}$	$15,8 * 10^{-5}$
$1 * 10^5$	$7,2 * 10^{-5}$	$26,4 * 10^{-5}$
$1,2 * 10^5$	$8,24 * 10^{-5}$	$44,3 * 10^{-5}$

Further, after the acceptance of model based on (7) and (8), analyses of risk function intensity λ are presented. Calculation results are listed in table 3.

Linear model: $\lambda_o = 3,04 * 10^{-5}$ 1/h; $b = 4 * 10^4$ h; $\lambda_1 = 4,08 * 10^{-5}$ 1/h.

Exponential model: $\lambda_1 = 5,6 * 10^{-5}$ 1/h; $\lambda_o = 3,36 * 10^{-5}$ 1/h.

NUREG/CR – 5378 parameter's presented results are compared with calculations offered in model considered as listed in table 3.

Table 3. Comparison of numerical and experimental results

t, h	λ, 1/h					
	Linear model			Exponential model		
	λ_{exp}	λ_{calc}	error, %	λ_{exp}	λ_{calc}	error, %
$2 * 10^4$	$3,04 * 10^{-5}$	$3,04 * 10^{-5}$		$3,36 * 10^{-5}$	$3,36 * 10^{-5}$	
$4 * 10^4$	$4,08 * 10^{-5}$	$4,08 * 10^{-5}$		$5,6 * 10^{-5}$	$5,6 * 10^{-5}$	
$6 * 10^4$	$5,12 * 10^{-5}$	$5,4 * 10^{-5}$	+5,5	$9,4 * 10^{-5}$	$9,2 * 10^{-5}$	-2,1
$8 * 10^4$	$6,16 * 10^{-5}$	$6,08 * 10^{-5}$	-1,3	$15,8 * 10^{-5}$	$15,2 * 10^{-5}$	-3,8
$1 * 10^5$	$7,2 * 10^{-5}$	$6,53 * 10^{-5}$	-9,3	$26,4 * 10^{-5}$	$24,8 * 10^{-5}$	-6,0
$1,2 * 10^5$	$8,24 * 10^{-5}$	$7,8 * 10^{-5}$	-5,3	$44,3 * 10^{-5}$	$40,8 * 10^{-5}$	-8,0

5. Results

1. Present study proposes a simplified approach for determination of failure risk intensity. The approach is applicable in the analysis of reliability of construction components that undergo aging due to vibrations.
2. When analyzing reliability, it is sufficient to possess experimental data in the beginning of component operation and subsequently failure risk intensity values are to be analyzed by the proposed model.
3. The applicability of the model in engineering problem solving is confirmed by comparison of experimental and theoretical values.

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