Accelerated Life Testing for Products Without Sequence Effect

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Key words: Accelerated testing, Reliability degradation, Degraded performance, Failure mode, Distribution (statistical), Reliability prediction.

SUMMARY & CONCLUSIONS

This paper proposes united accelerated life testing and accelerated degradation testing for a class of products without sequence effect. Comprehensive reliability models for the failure mode and performance degradation under different load conditions for these products are established in Ref. 1. The proposed accelerated testing based on the above models allows both:

a) to test the hypothesis of the products belonging to the considered class
b) to perform the reliability prediction and life estimation using the observed performance dagradation data.

Reliability characteristics for normal operating conditions and one-to-one transformation between performance degradation and cumulative distribution of failures independent of the load conditions is obtained from the testing results under more severe conditions.

1. INTRODUCTION

Accelerated life testing is an extremely important and rather complicated problem of reliability theory and practice. The primary goal of accelerated life test is to reduce time for estimation of required reliability characteristics under normal use conditions (environmental and operating stresses) based on the results of the considered product testing in more severe (accelerated) conditions. The solution of this problem is based on building transformation models from overstress to normal.

Frequently wear, fatigue, fracture, rupture, friability, corrosion, marginal and other various accelerated tests are considered in the accelerated life testing. These tests can be included in life testing only if there exists or may be established a certain dependence between considered performance degradation data and reliability characteristics. In this case accelerated degradation test has an essential advantage over ordinary accelerated life tests. These performance degradation data allow on one hand, to obtain more accurate reliability characteristics, and on the other hand, to be utilized directly in reliability prediction of these products during their operation.

The solution of these problems is considered for a cl products for which the degree of reliability degrac (operating performance in the sence of accumulated fr failed) at a given moment of time depends onl summarized operating time under each load conditior does not depend on their order, i.e., they do not h sequence effect
(Refs. 1-3). It is evident that this definition is valid und assumption that the load stresses are in a certain admi range. These items are termed PIOLC - Product Invaria Order of Load Condition. The considered class incluc large number of mechanical, electric, hydraulic and devices for which the main failure mechanisms are detern by wear, fatigue, corrosion, diffusion, etc.

As shown in Refs. 1-2, some products are not PIOL the regular time scale, but they can be studied as PIOL some transformation of time, e.g. on logarithmic or p time scale, etc. The criterion for selection of appropriate scale is proven in Ref. 1.

For many of the considered products it is often possib find some parameters which can be physically measurec calculated on the basis of measurements) and which reflec current state of cumulative reliability degradation determine the remaining life time of the product. Example such detecting parameters can be oil consumption of engine, output of a compressor, pressure in a hydra system, capacity of a battery, etc. As a rule, the functio change for these parameters describing the deteriora process are strictly monotonic in time. This is natural bec physical and/or chemical processes of reliability degrada are irreversible and their performance always monotonically worse. As a result, if one-to- correspondence between this parameter and cumulative lifetime distribution can be found, then parameter can be effectively used for description of current reliability state of the product and for prediction of remaining lifetime. In this case the specified parameter of product is called detecting (indicator) parameter and a char of this parameter is correspondingly called detecting indicator function. The knowledge of this detecting functi allows to deal with both sudden and gradual failures on common basis. Thus, the description of degradation acquir a dual nature: statistical and physical.

The ordering of the load conditions by their impact on ›rocesses leading to failures is performed in accordance with he so called accelerated principle. According to this principle ome load conditions are accelerating in relation to others if he probability of failure in the same given time is greater in irst over the second. For the considered class of products vorking in two different (fixed or cyclic) load conditions :onnected to the accelerating principle, the ratio of time to each equal probability of failure or equal level of detecting unction is a constant value. This statement is closely :onnected to well known laws such as Arrhenious, inverse ›ower, exponential, Eyring, etc., which apply to median or .verage time to failure exclusively for simple specimens material, units, elements, components, etc.) with one lominant failure mode and use numerical values of stresses.

The proposed models and corresponding accelerated life esting may be applied to significantly more complex products ınd load conditions and do not always require numerical epresentation of the load conditions.

NOTATION

.C	- Load Conditions
'IOLC	- Product Invariant to Order of LC
)L	- Degradation Level
:df	- Cumulative distribution function
ζ, Y, Z	- Vectors (tuples) of LC
ζ	- Range of admissible LC
$=F_X(t)$	- Cdf for lifetime under LC X
$_X(t)$	- Performance degradation of product operating under LC X
$\omega=\Phi_X(t)$	- Normalized equivalent transformation of product performance degradation over time t under LC X, Cdf
$=\Psi(\omega)$	- Transformation q to DL ω, Cdf
$\omega=\Psi^{-1}(q)$	- Inverse transformation DL ω to q, Cdf
$T_X^{(q)}=F_X^{-1}(q)$	- q fractile of Cdf $F_X(t)$
$T_X^{(\omega)}=\Phi_X^{-1}(\omega)$	- ω fractile of Cdf $\Phi_X(t)$
$Z > X$	- LC Z accelerated, more severe, in relation to LC X
$\zeta=Y$	- LC Y equivalent to LC X
$\zeta\approx Y$	- LC Y equivalent on the average to LC X

2. DEFINITIONS AND PREVIOUS RESULTS

Load conditions of an item are defined as a vector $\zeta(t)=X\{x_1(t), x_2(t),..., x_n(t)\}$ characterized by a set of specific ombinations of physical, chemical, electrical, thermal, nechanical stresses which represent an assembly of external ınd internal factors changing in time and affecting the ›roduct. LC are fixed if each component of this vector $x_i(t)=x_i$ s independent of time. In case of even one of the stress components deviating from the constant, LC is consider varying. The varying stress where the equality $X\{x_1(t), x_2(t),..., x_n(t)\}=X\{x_1(t+H), x_2(t+H),..., x_n(t+H)\}$ is val for all vector components defined as cyclic with period H.

Define load stress as operating condition $X(M$ corresponding to specific activity (mission, task, etc.) M performed by the considered product in the fixed duration If this product performs a set of same activities M_H, its LC a cyclic with period H.

If $T_X^{(q)}$ and $T_Z^{(q)}$ are q fractiles of lifetime Cc $q=F_X(t)$ and $q=F_Z(t)$ satisfies the inequality $T_Z^{(q)} < T_X^{(q)}$ f any $0<q<1$, then LC Z strictly more severe than LC X a therefore $Z > X$ (accelerated principle). Two LC X and Y a equivalent when $X = Y$, if equality $T_X^{(q)} = T_Y^{(q)}$ holds f all q. Two LC X and Y are equivalent on the average $X\approx$ when for any $0<q_0<1$ there exist $q_*>q_0$ for whi $T_X^{(q_*)} = T_Y^{(q_*)}$.

Let a product perform a certain sequence of activities und corresponding LC. If this product belongs to PIOLC class th it is possible to build for it a cyclically repeating load stre block equivalent on the average to the actual LC. Each loa stress of such block must correspond to the stresses of tl typical work scenario (mission benchmark). Specifically th matching includes all stresses and their relative duratic proportional to the time of their effect for the period considered sequence of mission performance. Choosing a loa stress block with the shortest possible period will achiev greater accuracy.

Let $\varepsilon_X(t)$ be monotonic performance degradation of son product under LC X. Let the function $\varepsilon_X(t)$ be limited on tl segment $[a,b]$ where the value a represents initial value of tl considered parameter and b represents the final valu corresponding to failure, i.e. when performance reaches tl failure level. This performance $\varepsilon_X(t)$ can be considere separately for each product or as an average function of son population of these products operating under LC X.

The change of $\varepsilon_X(t)$ through equivalent normalize transformation $\Phi_X(t) = \left|\frac{\varepsilon_X(t)-a}{b-a}\right|$ can be represent by corresponding Cdf $\omega=\Phi_X(t)$.

As was mentioned above, if between values $\varepsilon_X(t)$ a lifetime Cdf $F_X(t)$ exists a one-to-one correspondence, th $\varepsilon_X(t)$ is detecting function independent of the LC . Evidently, if the considered performance degradation $\varepsilon_X(t)$ a detecting function, then also $\omega=\Phi_X(t)$ is a detecting functio i.e. there exists a single-value function $q=\Psi(\omega)$ transformation q to DL ω and inverse transformation $\omega=$ $^1(q)$ of DL ω to q representing Cdfs.

The necessary and sufficient condition for the considere products to belong in PIOLC class in some range of loa stress E is for equality

$$F_Z(t) = F_X(ct) \quad ($$

to be true (first proven in Ref. 2), where $X, Z \in E$ are some fixed or cyclic LC and c is a constant depending only on the load stresses X and Z. In Ref. 1 this criterion is proven for detecting functions:

$$\varepsilon_Z(t) = \varepsilon_X(ct) \quad (2)$$

$$\Phi_Z(t) = \Phi_X(ct) \quad (3)$$

with same constant c, i.e. dependencies $\varepsilon_X(t)$ and $\Phi_X(t)$ are detecting functions if the following is true: eq (1) and eq (2) or eq (1) and eq (3).

Evidently, detecting functions describe changes in time on the current level of accumulated degradation. In this sense a time-to-failure Cdf is a trivial statistical "detecting" function of DL, when $\omega=q$.

If Cdf $\omega=\Phi_X(t)$ is a detecting function, then ω fractile $T_X^{(\omega)} = \Phi_X^{-1}(\omega)$ represents time measure until DL ω.

It is easy to prove that for PIOLC truncated Cdf

$q_{Tr} = F_{X|q_0} = F(\tau \mid t_0)$, $t_0 = T_X^{(q_0)}$ and

$\omega_{Tr} = \Phi_{X|\omega_0} = \Phi(\tau \mid t_0)$, $t_0 = T_X^{(\omega_0)}$ defining a

conditional measure of remaining time after the given value q_0 or DL ω_0 has already been achieved under LC X and Z and satisfies eq (1) and eq (3). See Ref. 1. This property makes possible to study reliability degradation of identical products for the same arbitrary levels treating them as initial and to align, if necessary, the initial levels, i.e. to reduce them to the similar starting state.

Evidently, the indicated above comparison of LC by their impact on reliability degradation based on lifetime Cdfs is equivalent to utilization of detecting functions, i.e. instead of q, $T_X^{(q)}$, $T_Z^{(q)}$ are used ω, $T_X^{(\omega)}$, $T_Z^{(\omega)}$.

In case when criteria for considered items belonging to PIOLC class is not met in regular time scale t there may exist any other scale $\tau=A(t)$ which is some monotonically increasing function, e.g. $\tau=a\log t$, $\tau=a^{\beta t}$, $\tau=at^{\beta}+\gamma$, etc., in which considered products will belong to PIOLC class. If $\xi=R_X(t)$ is a Cdf of parameter change level for products under the LC $X \in E$, then on scale $A(t)$ there is a corresponding Cdf $\xi=W_X[A(t)]=W_X(\tau)$. For the considered products to belong to PIOLC, it is necessary and sufficient for the inverse function $W_X^{-1}(\xi)$ under $X \subset E$ to be presented in the following way: $\tau = W_X^{-1}(\xi) = \dfrac{U(\xi)}{V(X)}$ where $U(\xi)$ and $V(X)$ are some monotonically increasing functions. See Ref. 1. From this Cdf $\xi=W_X(\tau)=\eta[A(t)V(X)]$ represents some distribution from multiplication of functions $A(t)$ and $V(X)$. Practical application of the specified criteria is restricted by the requirement to know about the type of Cdf $R_X(t)$.

3. ACCELERATED DEGRADATION TESTS AND RELIABILITY PREDICTION

A set of properties of items belonging to PIOLC allc construct various methods of accelerated testing. Sorr those methods are presented in Refs. 2-3. An innov approach to development of accelerated tests and advan gained in reliability prediction in cases of physi measurable changes of performance degradation is consic in this paper.

Suggested accelerated tests include identification c performance degradation and its checking against the indic criteria for detecting function.

Let us consider one of the most simple models fo accelerated reliability degradation test. Two lots of the prc under analysis are being tested. It is advisable to specimens simultaneously. Let us assume that generalized performance degradation characteristic has set for this product and that it changes monotonically time. Items in both lots should have homogeneous distribu of initial performance values. Specifically, estimates of m and standard deviations must be almost equal for both

Items of the first lot are tested under the fixed or c accelerated stress $Z > X$, $Z \in E$ where X is run conditions. This lot is being tested until all or almost al items fail. Items of the second lot are tested by same blocks each containing fixed or cyclic stress X or subblock equivalent on the average to LC X operating du time θ_X and afterwards accelerated LC Z during time θ_Z all or almost all items fail. For a test under cyclic stres length of the cycle must be much shorter than the r lifetime of considered items under this LC.

In both lots time to failure of each item must be recor The values of the performance characteristic $\varepsilon_i(t)$ for item must be recorded continuously or at least at the mor of each failure. When performance characteristic of any reaches the predefined limit b, i.e. $\varepsilon_i(t)=b$ it is treated failure and this item should be taken out of the tesi addition, the mean values of this key parameter corresponc to each of both lots $\overline{\varepsilon}^{(I)}(t)$ and $\overline{\varepsilon}^{(II)}(t)$ shoul calculated.

For each tested specimen i, for the values of performance degradation and for average values of characteristic for both lots there are found respec equivalent normalized values of DL ω: $\Phi_{(i)}(t)$, $\Phi^{(I)}(t)$, $\Phi^{(II)}(t)$. As a resul these tests there will be obtained:

- empirical lifetime Cdf or parts of this corresponding to censored data $q=\hat{F}^{(I)}(t)$, $q=\hat{F}^{(II)}(t)$ for the first second lots;
- empirical Cdf or parts of this Cdf for DL $\hat{\Phi}_{(i)}^{(I)}(t)$, $\hat{\Phi}_{(i)}^{(II)}(t)$, $\hat{\Phi}^{(I)}(t)$ and $\hat{\Phi}^{(II)}(t)$ for the first and second lots.

Analysis of the obtained results include testing of the lowing hypothesis:

1. Do the investigated items belong to the PIOLC class?
2. Does the function of the average value of observed generalized performance degradation represent an detecting function?
3. Do the functions of general performance degradation of each separate investigated specimen represent individual detecting functions?

To check the first hypothesis with the results from the :ond lot testing $\hat{T}_Z^{(q)\,II}$ is estimated:

$$\hat{T}_Z^{(q)\,II}=\frac{\theta+j\theta_Z(c-1)}{c}$$

$$\text{for } j(\theta_X+\theta_Z)\leq\theta<j(\theta_X+\theta_Z)+\theta_X$$

1 (4)

$$\hat{T}_Z^{(q)\,II}=\theta-\frac{(j+1)\theta_X(c-1)}{c}$$

$$\text{for } j(\theta_X+\theta_Z)+\theta_X\leq\theta<(j+1)(\theta_X+\theta_Z)$$

ere θ is the passing time, $c=\frac{T_X^{(q)}}{T_Z^{(q)}}$ some unknown istant, $j=0,1,2,\ldots$. The values $\hat{T}_Z^{(q)\,II}$ are found for the es θ corresponding to the failure moments of specimens of second lot. As a result, in contrast to empirical lifetime f obtained under LC Z during the testing of the first lot, ther empirical lifetime Cdf $\hat{F}_Z^{(II)}(t,c)$ or parts of ; Cdf, dependent on an unknown constant c will be found ler stress Z obtained from testing the second lot. If it is sible to determine a constant c for which s $\hat{F}_Z^{(I)}(t)$ and $\hat{F}_Z^{(II)}(t)$ will be homogeneous a sufficiently high level of confidence, then the considered is belong to the PIOLC class. Obviously, this hypothesis be rejected on the considered scale of time and be carried on another scale.

Traditional methods of statistical data analysis can be used est homogeneity. The most powerful test of this hypothesis well as selection of adaquate distribution function are ranteed by the bootstrap method (Refs. 2,4,5). In the case a positive result, the time scale and stant $c=\frac{T_X^{(q)}}{T_Z^{(q)}}$ for two LC $X < Z \in E$ will be ermined.

Now the second hypothesis on indicator function for sidered item population belonging to the PIOLC class can verified. The $T_Z^{(\omega)\,II}$ is calculated by the stated above (4) in which q is changed to ω. Those calculations are de for time values θ for which DL ω in the second lot was ermined. As a result, the obtained empirical Cdf or part of this Cdf $\hat{\Phi}_Z^{(II)}(t,c)$ is verified for homogeneity wit Cdf $\hat{\Phi}_Z^{(I)}(t)$ with the previously set constant c and tim scale.

If the tested hypothesis with the given confidence level i accepted, then based on the data resulting from the first lo testing or on the united data of this lot and calculated dat from the second lot transformation $q=\Psi(\omega)$ is found. Point q_i, ω_i of this curve are determined correspondingly with the equality $T_Z^{(q_i)}=T_Z^{(\omega_i)}$, $i=1,2,\ldots$. It allows to determine the probability of failure for the time in which the population of tested items reached a certain value of DL ω.

If both considered hypotheses are accepted and the realizations $\varepsilon_i^{(I)}(t)$ or $\hat{\Phi}_{(i)}^{(I)}(t)$ of the random function of performance of the first lot are not intensely interlaced in the set time scale then the hypothesis of individual indicator function existence for observed PIOLC is tested. For each specimen i of the second lot in accordance with the indicated above relation there is empirical Cdf or a part of it $\hat{\Phi}_{(i)}^{(II)}(t,c)$. For each # i this function is tested for homogeneity with Cdf $\hat{\Phi}_{(j)}^{(I)}(t)$ for specimen # j of the first lot that has the closest value of the general performance in the initial moment of time, i.e. $\varepsilon_i^{(I)}(0)\approx\varepsilon_j^{(II)}(0)$. If for most specimens of the second lot the given hypothesis is correct then the change of the general performance of the considered items is the individual indicator function.

In case where only the first hypothesis is accepted, the results of the conducted tests allow to determine the empirical lifetime Cdf for the investigated items under operational LC X according to the test data of accelerated the LC Z:

$q=\hat{F}_X(t)=\hat{F}_Z^{(I)}(\frac{t}{c})$ or by empirical Cdf $\hat{F}_Z(t)$ received from the combined data for Cdfs $\hat{F}_Z^{(I)}(t)$ and $\hat{F}_Z^{(II)}(t,c)$,

i.e. $q=\hat{F}_X(t)=\hat{F}_Z(\frac{t}{c})$ where c is the found constant.

For the observed group of identical items operating under arbitrary fixed or cyclic stress $X_0 \neq X$, reaching a certain number of failures corresponding to the level q_0 for the time period t_0 allows to determine a new constant c_0 where

$c_0=\frac{t_0}{T_X^{(q_0)}}$, $T_X^{(q_0)}=\hat{F}_X^{-1}(q_0)$. Then the lifetime Cdf under LC X_0 is $q=\hat{F}_{X_0}(t)=\hat{F}_X(\frac{t}{c_0})=\hat{F}_Z(\frac{t}{cc_0})$ and Cdf of remaining lifetime of those items is determined by truncation of the given distribution by $t=t_0$.

If the second hypothesis is correct, then for the considered task independent of the existence of failures at any arbitrary moment of time t_0 the average value of the performance $\bar{\varepsilon}(t_0)$ is calculated and, accordingly the DL ω_0 is reached. The new constant c_0 is determined from the equality $c_0 = \dfrac{t_0}{T_X^{(\omega_0)}} = \dfrac{t_0}{cT_Z^{(\omega_0)}}$ in which $T_X^{(\omega_0)} = cT_Z^{(\omega_0)} = c\Phi_Z^{-1}(\omega_0)$, where c is a found constant. Empirical lifetime Cdf of the investigated items under LC X_0 is defined by the relationship $q = \Psi[\Phi_Z(\dfrac{t}{cc_0})]$, and the residual lifetime of those items under LC X_0 are distributed according to the same Cdf truncated by $t=t_0$.

In case when the third hypothesis is correct, i.e. a performance degradation change for considered items is an individual detecting function, then estimation and prediction reliability for such items under fixed or cyclic LC X_0 can be done individually for each item. For any item for which reliability is required to be estimated, an item with the initial value of general performance closest to the initial value $\varepsilon(0)$ for the item under investigation is selected from both tested lots. The considered task is solved identically to the previous case. The basis for the solution serves as a corresponding characteristic of the selected item.

Thus, if the function change of the generalized parameter is a detecting function, then performance degradation for PIOLC can be analyzed prior to any specimens failure. This is done by extrapolating performance degradation on the basis of $q=\Psi(\omega)$ transformation which allows to estimate the time to failure and other reliability characteristics. The possibility of detecting function utilization creates great advantages for receiving required reliability estimates and establishing relationships between performance, age, life distribution and load stresses.

Evidently, for all resulting empirical Cdf any required statistics:
mean lifetime, remaining mean lifetime, fractile, variance, etc., can be estimated. The bootstrap method allows selection of a suitable theoretical Cdf for the resulting empirical Cdf or their parts (Refs. 2,4,5). In this case, in the previously obtained relations all empirical Cdf are replaced by corresponding theoretical Cdf.

3.1 Example

Two lots of identical items were simultaneously tested. Each lot contained 20 specimens. The first lot was tested until all specimens failed under accelerated stress $Z > X$, where X is normal stress. The test results of the first lot are presented in Table 1.

The second lot was tested by similar load blocks until 16 of the specimens failed. Each block contained stress X operating during time $\theta_X=30$ and afterwards accelerated LC Z during time $\theta_Z=10$. The test results of the second lot are presented in Table 2.

Accelerated coefficient $c_i = c_{(T)}^{(q_i)}$ was calculated for each of the 16 failed specimens of the second lot. coefficients are found in accordance with eq (4) as fo

$$c_i = \frac{\theta_i - (j-1)\theta_Z}{T_Z^{(q_i)} - (j-1)\theta_Z}$$

if the failure occurred on the j-th cycle under stress X

$$c_i = \frac{j\theta_X}{T_Z^{(q_i)} + j\theta_X - \theta_i}$$

if the failure occurred on the j-th cycle under stress Z, θ_i is the time of i-th failure during the second lot corresponding to q_i. These calculated coefficients an corresponding q_i fractiles of lifetime $T_X^{(q_i)}$ are preser Table 3.

Table 1 - First lot test results

i	q	$\bar{\varepsilon}$	$\bar{\omega}$	T_z
1	0.071	87.6	0.268	76
2	0.119	94.3	0.291	108
3	0.167	100.6	0.312	129
4	0.214	105.2	0.328	146
5	0.262	110.4	0.346	160
6	0.309	114.3	0.360	173
7	0.357	120.1	0.380	185
8	0.405	123.8	0.392	196
9	0.452	130.5	0.416	207
10	0.500	137.4	0.440	219
11	0.548	145.2	0.466	228
12	0.595	154.7	0.499	239
13	0.643	165.1	0.535	250
14	0.690	177.3	0.577	262
15	0.738	190.2	0.621	274
16	0.786	199.8	0.654	288
17	0.833	217.1	0.714	303
18	0.881	232.6	0.768	322
19	0.929	246.4	0.815	346
20	0.976	299.5	0.998	389

$q = \dfrac{i+0.5}{n+1}$, n=max i

$\bar{\varepsilon}$ - average values of performance degradation

$\bar{\omega}$ - normalized average values of performance degradation

Table 2 - Second lc test results

i	q	$\bar{\varepsilon}$	$\bar{\omega}$	Cycle j
1	0.071	87.3	0.266	4
2	0.119	95.0	0.293	5
3	0.167	99.8	0.310	7
4	0.214	104.5	0.326	7
5	0.262	109.7	0.344	8
6	0.309	115.9	0.365	9
7	0.357	122.2	0.387	10
8	0.405	126.5	0.402	10
9	0.452	131.3	0.418	11
10	0.500	137.0	0.438	11
11	0.548	143.6	0.461	12
12	0.595	156.4	0.505	12
13	0.643	167.8	0.544	13
14	0.690	179.2	0.583	14
15	0.738	188.3	0.615	14
16	0.786	196.4	0.643	15

The rest of the items are withdrawn from further observation.

As the resulting estimates show, c_i are not constant, i.e investigated items do not belong to PIOLC class on a re time scale. However, on a scale lnT these items belor PIOLC, because $c_{(\ln T)}^{(q_i)} = \dfrac{\ln T_X^{(q_i)}}{\ln T_Z^{(q_i)}} \approx 1.2 = const$ Table 3). This allows to estimate the missing fractiles ir X: $T_X^{(q_i)} = \exp(1.2 \ln T_Z^{(q_i)})$ for i from 17 to presented in the lower part of Table 3. The theoretical C e established by the obtained full value samples of time to ilure under LC Z and X:

$$F_Z(t) = 1 - \exp(-\alpha_Z t^{\beta_Z}) =$$
$$= 1 - \exp(6.25 * 10^{-8} t^{3}) \quad ,$$
$$F_X(t) = 1 - \exp(-\alpha_X t^{\beta_X}) =$$
$$= 1 - \exp(6.25 * 10^{-8} t^{2.5})$$

. the Weibul laws with identical parameter $\alpha_X = \alpha_Z = 6.25*10^{-8}$. milar calculations for average values of the observed rformance degradation $\bar{\omega}$ are presented in Table 4.

Table 3 - Accelerated coefficients for time to failure under LC X, Z

i	q	$C_{(T)}^{(q)}$	$T_X^{(q)}$	$C_{(\ln T)}^{(q)}$
1	0.071	2.37	180	1.199
2	0.119	2.54	274	1.199
3	0.167	2.64	341	1.999
4	0.214	2.69	393	1.999
5	0.262	2.76	442	1.200
6	0.309	2.80	484	1.200
7	0.357	2.85	527	1.201
8	0.405	2.89	566	1.201
9	0.452	2.92	604	1.201
10	0.500	2.95	646	1.201
11	0.548	2.98	679	1.201
12	0.595	3.02	722	1.202
13	0.643	3.02	755	1.200
14	0.690	3.04	796	1.200
15	0.738	3.06	838	1.199
16	0.786	3.08	887	1.199
17	0.833		950	1.200
18	0.881		1022	1.200
19	0.929		1114	1.200
20	0.976		1282	1.200

he values of $\bar{\omega}$ during the second lot testing do not incide with the average values of observed performance gradation obtained during the first lot testing. Therefore for lculation of $T_Z^{(\bar{\omega})}$ in Table 4 the linear approximation of lues in Table 1 was used. The obtained constant value of celeration coefficient $C_{(\ln T)}^{(\bar{\omega})} = 1.2$ on logarithmic time ale establishes the fact that the change of the considered erage of performance degradation represents the detection nction. The united data from the test results of the first lot d calculated test results of the second lot are presented in able 5.

Table 4 - Accelerated coefficients and empirical Cdf for normalized average performance degradation under LC X, Z

i	$\bar{\omega}$	$T_Z^{(\bar{\omega})}$	$C_{(T)}^{(\bar{\omega})}$	$T_X^{(\bar{\omega})}$	$C_{(\ln T)}^{(\bar{\omega})}$
1	0.266	74.6	2.44	182	1.207
2	0.293	110.3	2.45	270	1.190
3	0.310	126.3	2.75	347	1.209
4	0.326	143.5	2.78	399	1.206
5	0.344	158.1	2.82	446	1.205
6	0.365	176.3	2.70	476	1.192
7	0.387	191.2	2.68	512	1.188
8	0.402	200.4	2.77	555	1.192
9	0.418	208.4	2.89	602	1.199
10	0.438	218.1	2.97	648	1.202
11	0.461	226.1	3.03	685	1.204
12	0.505	240.8	2.98	718	1.199
13	0.544	252.7	2.96	748	1.196
14	0.583	263.8	3.00	791	1.197
15	0.615	272.2	3.11	846	1.202
16	0.643	283.0	3.19	903	1.206
17	0.714	303		950	1.200
18	0.768	322		1022	1.200
19	0.815	346		1144	1.200
20	0.998	389		1282	1.200

Table 5 - United test result data from both lots

i	q	$\bar{\omega}$	T_z	T_x
1	0.037	0.266	74.6	177
2	0.061	0.268	76	181
3	0.085	0.291	108	275
4	0.110	0.293	110.3	282
5	0.134	0.310	126.3	332
6	0.158	0.312	129	341
7	0.183	0.326	143.5	387
8	0.207	0.328	146	396
9	0.232	0.344	158.1	435
10	0.256	0.346	160	441
11	0.280	0.360	173	485
12	0.305	0.365	176.3	496
13	0.329	0.380	185	525
14	0.354	0.387	191.2	547
15	0.378	0.392	196	563
16	0.402	0.402	200.4	578
17	0.427	0.416	207	601
18	0.451	0.418	208.4	606
19	0.476	0.438	218.1	640
20	0.500	0.440	219	644
21	0.524	0.461	226.1	669
22	0.549	0.466	228	675
23	0.573	0.499	239	715
24	0.598	0.505	240.8	722
25	0.622	0.535	250	754
26	0.646	0.544	252.7	764
27	0.671	0.577	262	798
28	0.695	0.583	263.8	804
29	0.719	0.615	272.2	835
30	0.744	0.621	274	842
31	0.768	0.643	283.0	875
32	Censored data			
33	Censored data			
34	Censored data			
35	Censored data			
36	0.810	0.654	288	894
37	0.852	0.714	303	950
38	0.894	0.768	322	1022
39	0.936	0.815	346	1114
40	0.979	0.988	389	1282

Because the values corresponding i from 32 to 35 represen censored data, the Kaplan - Meier estimator (KME) is used t determine the q_i for i from 36 to 40. For the considere $q_i = \dfrac{i+0.5}{n+1}$, where n is the sum of all teste specimens, the KME for numbers i following after censored data is as follows: $q_i = 1 - (1 - q_k)\ (\frac{n-i+0.5}{n-i+1.5})$

where $k < i$ is the last of the numbers prior to i for the uncensored data. Empirical lifetime Cdf under LC X, Z and dual transformation of detection function $\overline{\omega}$ and q are correspondingly represented on Figures 1 and 2.

Suggested method of accelerated tests can be improved by uniformly randomizing the time θ_X and θ_Z during second party specimen testing, with stipulation that their sum $\theta_X+\theta_Z$ has to be negligible compared to mean life time of considered specimens under the indicated LC.

In accordance with the set reliability models for PIOLC it is possible to propose several other plans of accelerated testing encompassing a large area of LC, various methods of stress alternation, different sequences of tested lots, and also plans which take into consideration the results from previous test stages.

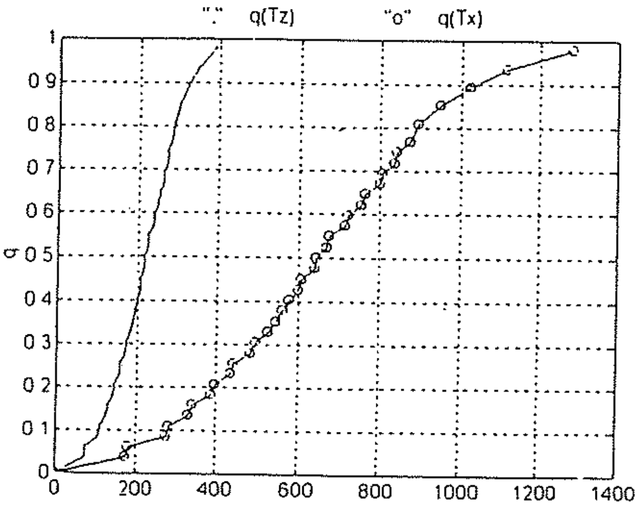

Figure 1. Empirical lifetime Cdfs under LC X, Z

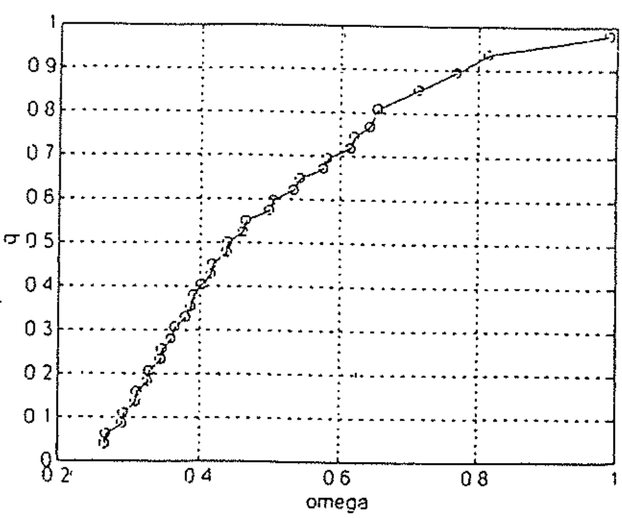

Figure 2. Dual transformation of detecting functions $\overline{\omega}$ and q

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