# QUICKENED DEFINING TESTS WITH LIMITING COMBINED REGIMENS

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**Summary**. Method peculiarities of quickened tests for dependability of machine elements in limiting combined regimens are propounded. The possibility of introduction of method of standardization in agricultural machinery industry is grounded.

**Key words:** Tests, combined regiments, linear summation, reliability.

## INTRODUCTION

Quickening of defining tests performance for machines dependability and their parts requires solving of many technical and methodological problems. The necessity to meet the requirements of physical similarity of failures emerging in their real exploitation and during test performance and, at the same time having the possibility of quick determination of failures whereby prognosis of dependability measures which are expected from the item in the regimens of its real operation, is the key problem [4,5,13,15]. In many cases it is possible to meet these requirements applying limiting combined regimens of quickened tests [6,7]. Different ways of realization of such approach and possibilities of standardization of methods of measures determination of mechanic dependability due to the tests results are presented.

## EXPOSITION OF BASIC MATERYALU

Mobile agricultural and transportation machines are usually used in several regimens which are quite different according to their damaging effect upon machine parts. Being informed about major damaging effects and regimens emerging in their real exploitation, it is necessary before defining tests performance to analyze the damaging effect of each of item regimens. The real range of possible exploitation regimens due to damaging effect should be divided into two components. One or several extreme regimens causing the most intensive accumulation of the item's mechanical failures must be referred to quickened regimen during its tests. The rest bulk of regimens is referred to the second component, i.e. complementary test regimen. Limiting combined test regimen is formed from these two components which are emerged in certain proportion.

Planned quantity of item's samples for tests is divided into some groups. Each group is tested in certain combined regimen which differs from one another by operating time of the item running in quickened regimen. Quickening principle of tests means that the share of quickened regimen is always larger than that in the conditions of real exploitation. Each sample is tested until mechanical failure emerging or preset limiting damage level. The condition of physical similarity of failures must be performed to some extent due to the fact that limiting combined test regimens consist of those regimens which emerge in the real exploitation. But at the same time physical similarity of damages must be monitored according to their main parameters in order not to exaggerate allowable value of share of quickened regimen. During tests processes it is necessary to ensure sufficiently great quantity of serial changes of quickened regimen from complementary one and vice versa.

Taking into account said above, tests give the possibility of quickened determination or prognosis of mechanic dependability measures. It is better to use famous linear hypothesis of mechanic failures accumulation [1,2,8,9, 16,17,18] which is widely used during test and calculations for fatigue test. Mathematic formula corresponding to this hypothesis looks like the following:

$$\frac{\bar{t}_1}{T_1} + \frac{\bar{t}_2}{T_2} = 1, \qquad (1)$$

where: $\bar{t}_1$ - is the mean component of operating time to failure emerged in quickened regimen; $\bar{t}_2$ - the mean component of operating time to failure emerged in complementary regimen; $T_1$ - the mean item operating time to failure emerged only in quickened regimen; $T_2$ - the mean item operating time to failure emerged only in complementary regimen.

Values $\bar{t}_1$ and $\bar{t}_2$ characterizes the item dependability during its operation in preset combined regimen, their sum equals certain value of the mean operating time to failure. There is geometric interpretation of the ratio (1) due to which it should be considered as linear regressive dependence with parameters $T_1$ and $T_2$ which can be found as the result of lifetime tests performed in several combined regimens. Each of these regimens is characterized by certain value of a share of realization of quickened regimen in it.

The results of tests in limiting combined regimens are selective mean components of operating time to failure: $\bar{t}_{1i}$ – in quickened regimen and $\bar{t}_{2i}$ – in complementary regimen which correspond to preset values of $\alpha_i$ share of quickening component in the combined regimen. Test quickening is ensured by obligatory conditions observing: $\alpha_i > \alpha^*$, where $\alpha^*$ is the mean share of quickened regimen during the item real exploitation.

Considering (1) as the linear regression equation, it can be accepted like orthogonal one [6]. Such assumption needs calculations of the mean operating time to failure or the mean lifetime in the following consequence:

* general mean components of operating time to failure in quickened and complementary regimens are determined due to test results:

$$\bar{\bar{t}}_1 = \sum_{i=1}^{k} \omega_i \bar{t}_{1i}; \qquad \bar{\bar{t}}_2 = \sum_{i=1}^{k} \omega_i \bar{t}_{2i}, \qquad (2)$$

where: $\omega_i = \dfrac{n_i}{N}$ - "weight"coefficients,

$N = n_1 + n_2 + ... + n_k$ - general amount of item tested samples,

the sum value is calculated $S = \sum_{i=1}^{k} \omega_i \bar{t}_{1i} \bar{t}_{2i}$

and compared with its derivative $\bar{\bar{t}}_1 \cdot \bar{\bar{t}}_2$,

if $S < \bar{\bar{t}}_1 \cdot \bar{\bar{t}}_2$, complementary coefficients are defined:

$$\chi = \frac{\sum_{i=1}^{k} \omega_i (\bar{t}_{2i})^2 - \sum_{i=1}^{k} \omega_i (\bar{t}_{1i})^2 + (\bar{\bar{t}}_1)^2 - (\bar{\bar{t}}_2)^2}{2(\bar{\bar{t}}_1 \cdot \bar{\bar{t}}_2 - S)}, \qquad (3)$$

$$\beta = \sqrt{1 + \chi^2} - \chi. \qquad (4)$$

and then the mean time operating to failure in the conditions of real exploitation is predicted whereby the formula:

$$T = \frac{\bar{\bar{t}}_1 + \beta \bar{\bar{t}}_2}{\beta + \alpha^*(1 - \beta)}, \qquad (5)$$

if $S \geq \bar{\bar{t}}_1 \cdot \bar{\bar{t}}_2$, it means that performed tests did not detect damaging action of complementary regimen, thus predicted mean operating time to failure is determined by the formula:

$$T = \bar{\bar{t}}_1 \big/ \alpha^*. \qquad (6)$$

Prediction of gamma-percent measures: gamma-percent lifetime or operating time to failure can be defined by general formula [3]:

$$T_\gamma = T \cdot \theta(\gamma, V_t), \qquad (7)$$

where: $\theta(\gamma, V_t)$ - coefficient which depends on reliability function $\gamma$, expected coefficient in variation of resource $V_t$ and the kind of reliability function distribution.

The value $\theta(\gamma, V_t)$ for most widely used laws of reliability function distribution is calculated by the following formulae:

normal distribution

$$\theta_н = 1 - U_\gamma V_t, \qquad (8)$$

where: $U_\gamma$ - quantile of normal distribution;

logarithmically normal distribution

$$\theta_л = \left\{\sqrt{1 + V_t^2} \exp\left[U_\gamma \sqrt{\ln(1 + V_t^2)}\right]\right\}^{-1}. \qquad (9)$$

Veibul distribution:

$$\theta_B = \frac{(\ln 1/\gamma)^{1/b}}{\Gamma(1 + 1/b)}, \qquad (10)$$

where: $b \approx \dfrac{1{,}126}{V_t} + \dfrac{0{,}011}{V_t^2} - 0{,}137$.

In practice the engineer very often does not have exact information about expected distribution type to failure or item useful life in exploitation conditions. Taking into account the possibility of such uncertainty, from the perspective of ensuring granted from exaggerated prognosis of gamma-percent measures, it is reasonably to use (7) to determine the coefficient this way $\theta(\gamma, V_t)$ to meet the requirement of: $\theta(\gamma, V_t) = \min\{\theta_н, \theta_л, \theta_в\}$. Harmonized meanings of this “minimized” by three distributions of the coefficient are presented in the Table. They depend on the variation coefficient $V_t$ and reliability function γ.

The analysis of statistic data about the item useful life which is similar by design and parameters with its previous analogue can provide us with the most faithful information as for the coefficient variations $V_t$ which has been exploiting for a long time in the same conditions as the item being tested. If it is necessary, the data concerning coefficients value $V_t$ which depend on the machine element and damage process type can be found in works [10,11,12,14,19].

Table 1. Minimized coefficient $\theta$

| $V_T$ | Γ, % | | | | |
|---|---|---|---|---|---|
| | 50 | 80 | 90 | 95 | 99 |
| 0,20 | 0,981 | 0,830 | 0,733 | 0,647 | 0,489 |
| 0,25 | 0,970 | 0,787 | 0,667 | 0,569 | 0,398 |
| 0,30 | 0,958 | 0,740 | 0,604 | 0,498 | 0,302 |
| 0,40 | 0,928 | 0,645 | 0,488 | 0,374 | 0,204 |
| 0,50 | 0,894 | 0,553 | 0,387 | 0,274 | 0,126 |
| 0,60 | 0,857 | 0,468 | 0,302 | 0,199 | 0,077 |
| 0,70 | 0,819 | 0,392 | 0,234 | 0,142 | 0,046 |
| 0,80 | 0,781 | 0,326 | 0,180 | 0,101 | 0,028 |
| 0,90 | 0,743 | 0,270 | 0,138 | 0,072 | 0,017 |
| 1,00 | 0,693 | 0,223 | 0,105 | 0,051 | 0,010 |

Realization of the method described above concerning the prognosis dependability measures due to the results of quickened test is illustrated by the following example. Useful time of impeller of water ring vacuum pump of the unit for individual milking is defined by leftover deformation of the polymer creep which it is made of. Damage is caused by complex action of mechanic load and the temperature influence of working fluid upon the blades under specified pressure level in the pump. But except specified exploitation regimen of operation, the pump impeller is running in extreme regimen for some time period (nearly 2%) during the pump preparation for running and its starting etc. Thus, during the exploitation two-stage regimen scheme of impeller operation is observed. This scheme was taken into account during planning and conducting quickened tests in combined regimens for determination of the mean gamma-percent useful life of impeller. Tests were conducted until gaining limited state when left over deformation of the blade exceeded minimal clearance between impeller and the pump body.

Four series of tests of impeller blades were performed with different time share in extreme (quickened) regimen. Obtained data are presented in the Table 2.

Determination of values of general mean of useful life components gained in quickened $\bar{\bar{t}}_1$ and complementary regimens $\bar{\bar{t}}_2$ are estimated by the following formulae (2):

$$\bar{\bar{t}}_1 = 0{,}158 \cdot 154 + 0{,}210 \cdot 153 + 0{,}316 \cdot 141 + $$
$$+ 0{,}316 \cdot 147 = 147 \text{ hours}$$
$$\bar{\bar{t}}_2 = 0{,}210 \cdot 173 + 0{,}316 \cdot 419 + $$
$$+ 0{,}316 \cdot 520 = 333 \text{ hours}$$

Table 2

| Number of blades $n_i$ | Weight coefficients $\omega_i$ | Operation share in quickened regimen $\alpha_i$ | Operating time to limited state, hours. | |
|---|---|---|---|---|
| | | | Quickened regimen $\bar{t}_1$ | Complementary regimen $\bar{t}_2$ |
| 3 | 0,158 | 1 | 154 | 0 |
| 4 | 0,210 | 0,47 | 153 | 173 |
| 6 | 0,316 | 0,25 | 141 | 419 |
| 6 | 0,316 | 0,22 | 147 | 520 |

Then the sum $S$ = 48382 and derivative $\bar{\bar{t}}_1 \cdot \bar{\bar{t}}_2 = 48951$ are calculated. The condition $\bar{\bar{t}}_1 \cdot \bar{\bar{t}}_2 > S$ is taking into account that means that complementary test regimen was damaging for impeller. That is why after sum calculations of squares $\sum_{i=1}^{4} \omega_i (\bar{t}_{1i})^2 = 21773$ i $\sum_{i=1}^{4} \omega_i (\bar{t}_{2i})^2 = 147208$ whereby formulae (3) and (4) optional coefficients are defined:

$$\chi = \frac{147208 - 21773 + 147^2 - 333^2}{2(48951 - 48382)} = 31{,}77,$$

$$\beta = \sqrt{1 + 31{,}77^2} - 31{,}77 = 0{,}015734.$$

Taking into account that share of pump operation in quickened regimen in real conditions of its operation is approximately 2% (i.e. $\alpha^* = 0{,}02$), prognosis value of mean impeller useful time is calculated (5)

$$T = \frac{147 + 0{,}015734 \cdot 333}{0{,}015734 + 0{,}02(1 - 0{,}015734)} = 4298 \text{ hours}$$

Due to findings about the process of damage it is possible to accept variation coefficient $V_t = 0{,}2$. Then, according to data of the Table 1, prognosis values of gamma-percent of useful life of impeller are calculated for $\gamma = 80$ and 99%, therefore:

$$T_{80} = 4298 \cdot 0{,}83 = 3567 \text{ hours},$$

$$T_{99} = 4298 \cdot 0{,}489 = 2102 \text{ hours}.$$

Thus, the results of conducted tests display that granted with high probability (99%) the impeller useful time must exceed 2 thousand hours of milking unit operation. Mean time of tests was 480 hours.

## CONCLUSIONS

The technique of conduction of quickened definitive tests of machine elements to dependability in limited combined regimens has universal character. Due to tests results the technique allows to apply clear statistic algorithm which does not require the usage of preset coefficients of test quickening like the standard [20] does. The technique is considered to be perspective from the point of view of supplying new information and improvements of the system of the branch standards on dependability of agricultural machinery which is needed during conducting of certification tests.

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## УСКОРЕНЫЕ ОПРЕДЕЛИТЕЛЬНЫЕ ИСПЫТАНИЯ С ПРЕДЕЛЬНЫМИ КОМБИНИРОВАННЫМИ РЕЖИМАМИ

**Аннотация.** Изложено содержание и рассмотренные особенности метода ускоренных определительных испытаний на надежность элементов машин в предельных комбинированных режимах. Указано на возможности стандартизации метода в отрасли сельскохозяйственного машиностроения.

**Ключевые слова**: Испытания, комбинированные режимы, линейное суммирование, надежность.