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CONDITION-BASED REPLACEMENT POLICY FOR PERIODIC UNIT INSPECTIONS TAKING INTO ACCOUNT LATENT STAGE OF DEFECT DEVELOPMENT

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In this article the maintenance policy for stochastically deteriorating unit with latent stage of defect development (such as pitting) are investigated. The failure probability, the probability of preventive replacement and residual operating life depending on the inspection period, the preventive and corrective replacement thresholds and the degradation rate are defined. The presented dependences may be used at optimization of agricultural machines maintenance.
Keywords: *maintenance policy, replacement threshold, failure, pitting*

Problem. Failures of the agricultural machinery units lead to the suspension of technological operations and loss the part of yield. To prevent failures make units diagnostics and replace them if the defects feature exceeds the preventive replacement threshold.

Research of a optimal replacement policy for units, failures of which occurs as a result of the parts wear started in works of V. M. Mihlin. These techniques are designed for parts where the wear starts when unit put into operation.

The effectiveness of transition from corrective repairs to condition-based maintenance depends on a replacement policy and its parameters (preventive replacement threshold and inspection periodicity). Thus, a prerequisite for efficient condition-based maintenance is optimal choice of these parameters.

Analysis of recent research and publications. In [1, 2] discussed ways to implement preventive replacement units by means of multiple measuring feature, determining its trend and forecasting residual life. The disadvantage of these methods is the relative complexity of implementation. In [3, 4] investigated replacement policies based on regular units inspections and comparing the current value of feature with a predetermined preventive replacement threshold. The advantage of these policies is the simplified procedure and requirements for diagnostic devices. Modeling of degradation processes is carried out using random unitary functions or using stochastic increases. These methods are designed for use in diagnostic of degradation that starts at the beginning of the exploitation. But a significant part of the failures are occurring due to defects, which is inherent in the latent stage of development (pitting, for example). Identifying trends of such defects is difficult, prompting the development of replacement policies based on a single inspection result.

Unresolved part of the problem is to determine the probability parameters of the replacement policies taking into account latent stage of defect development.

The purpose of this study is to determine the probability parameters of the replacement policies based on condition, with the periodic unit inspections of an agricultural machinery in the presence of latent stage of the defect development.

Model of development the defect and condition-based replacement policy. We assume that at the end of the latent phase defect is random initial size that does not exceed the preventive replacement threshold. To simulate the further defect development we shall be using the linear random function of time. The random parameter of this function is the rate of increasing of the defect (degradation rate). We assume that this rate does not depend on the defect size and the same is to complete the degradation process. The degradation rate depends on many factors, the combined effect of which is typically expressed with their product. Thus, we assume that the degradation rate are distributed according to logarithmically normal law:

$$f_v(v) = \frac{1}{\sqrt{2\pi}\, s_v v} \exp\left(-\frac{(\ln v - \ln M_v)^2}{2 s_v^2} \right) , \tag{1}$$

where f_v is the probability density of the degradation rate, s; M_v is the mode of the degradation rate, 1/s; s_v is the shape parameter of the degradation rate distribution.

If the defect size exceeds the preventive replacement threshold at inspection, unit is replaced with a new one. If the defect size has reached the correction replacement threshold during the technological operation, the failure occurs, after which the unit also is replaced with a new one. We assume that failure intensity is constant.

Determine of probability unit replacement. We assume that the previous inspection occurred at the beginning of time counting. We shall consider the development of defects during the next inspection period. Since defects have different sizes after latent stage of development should be considered in the final stage, when they exceed the preventive replacement threshold. Time when the defect size reaches the preventive replacement threshold, we signed as the moment of arising of the defect.

Suppose defect has arisen at the interval between inspections. If defect has arisen, it can lead to the unit failure or its preventive replacement. To unit was replaced by the result of inspection, the defect must have the degradation rate of a certain range. Specifically, the rate should be such that the defect size at next inspection is ranged from preventive replacement threshold to corrective replacement threshold. The lower limit of this range is zero. The upper limit we can find by the formula:

$$V_{\max} = \frac{D_C - D_P}{T_I - t_D} \ , \tag{2}$$

where $V_{\max}$ is the maximum degradation rate, 1/s; D_C is the corrective replacement threshold; D_P is the preventive replacement threshold; T_I is the inspection period, s; t_D is time of arising of the defect, s.

Determine the replacement probability, integrating over time and over degradation rate:

$$f_t = \frac{1}{T_I} \ , \tag{3}$$

$$P_R = \int_0^{T_I} \int_0^{V_{\max}(t_D)} f_v(v)\, f_t dv\, dt_D = \frac{1}{T_I} \int_0^{T_I} \left(\frac{1}{2} + \Phi\left(n\left(\frac{D_C - D_P}{(T_I - t)\, M_v} \right) / s_v \right) \right) dt_D \ , \tag{4}$$

where f_t is the probability density of time of arising of the defect, 1/s; P_R - is the replacement probability.

We turn to the relative time values (making normalization to inspection period), and pass from the distribution shape to the degradation rate variation coefficient:

$$\theta = \frac{D_C - D_P}{\mathbf{E}[v]} \ , \tag{5}$$

$$\Theta = \frac{T_I}{\theta} \ , \tag{6}$$

$$P_R(\Theta, c_v) = \int_0^1 \left(\frac{1}{2} + \Phi\left(\ln\left(\frac{c_v^2 + 1}{(1 - t')\Theta} \right) / \sqrt{\ln(c_v^2 + 1)} \right) \right) dt' \ , \tag{7}$$

where θ is the average duration of the defect development from the preventive replacement threshold to the corrective replacement threshold, s; Θ is the relative duration of the inspection period; t' is the relative time; c_v is the degradation rate variation coefficient;

Determine the unit failure probability:

$$P_F(\Theta, c_v) = 1 - P_R(\Theta, c_v) \ , \tag{8}$$

where P_F is the unit failure probability.

Calculate the residual operating life of the unit, if the defect has arisen at a some time moment and has a some degradation rate:

$$\Delta T(t_D, v) = \frac{D_C - D_I}{v} = \frac{D_C - (D_P + v(T_I - t_D))}{v} \quad , \tag{9}$$

where ΔT is the residual operating life, s; D_I is the defect size at inspection.

Determine the average residual operating life of units replaced by the inspection result:

$$\Delta T_R = \frac{\int_0^{T_I} \int_0^{V_{\max}(t_D)} f_v(v) f_t \, \Delta t(t_D, v) \, dv \, dt_D}{P_R} \quad , \tag{10}$$

where ΔT_R is the average residual operating life of the replaced units, *s*.

Yield losses depend on the field area part, treated to failure [5]. Define the operating time from the last inspection to the unit failure and lower limit of the rate degradation, the excess of which leads to failure:

$$\Delta t(t_D, v) = t_D + \frac{D_C - D_P}{v}, \tag{11}$$

$$V_{\min} = \frac{D_C - D_P}{T_I - t_D}, \tag{12}$$

where Δt is the operating time from the last inspection to the unit failure, *s*; $V_{\min}$ is the minimum degradation rate, 1/*s*.

We define the mean operating time from the last inspection to the unit failure:

$$\mathbf{E}[\Delta t] = \int_0^{T_I} \int_{V_{\min}(t_D)}^{\infty} \Delta t(t_D, v) f_v(v) f_t \, dv \, dt_D \, / \, P_F \, , \tag{13}$$

Consider the case when inspection period is equal to the duration of technological operations of crop. Calculate the expected value of the part of the field area treated to failure:

$$\mathbf{E}[\phi] = \frac{\mathbf{E}[\Delta t]}{T_I} \quad , \tag{14}$$

where φ is the part of the field area treated before the failure;

Calculate the expectation of yield losses due to failure in accordance with article [5] (graphs of $K(\Theta, c_v)$ are shown in Fig. 1):

$$\mathbf{E}[\Delta\kappa] = wT_I P_F k_1 \mathbf{E}[\tau](1-\mathbf{E}[\varphi]) = KwT_I k_1 \mathbf{E}[\tau] \ , \tag{15}$$

$$K = P_F(1-\mathbf{E}[\phi]) \ , \tag{16}$$

where w is failure intensity, 1/s; k_1 is the proportionality factor, 1/s; τ is recovery duration, s; K is the loss coefficient.

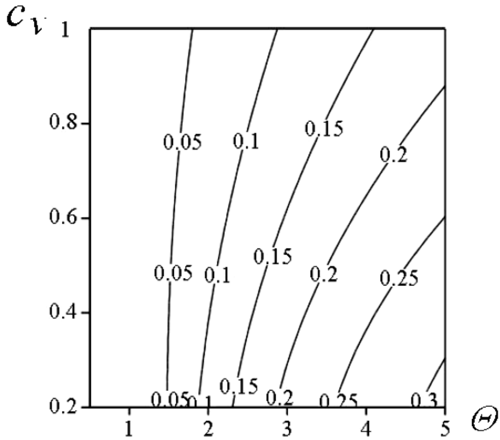

Fig. 1. The iso-level curves of the loss coefficient $K(\Theta, c_v)$.

Conclusions. Dependences of properties of condition-based replacement policy, depending on its parameters (period of inspection, preventive and corrective thresholds replacements) and units degradation rate are presented. This allows to determine the probabilities of failure and preventive replacement and the average yield loss due to failure Prospects for future research is to optimize the inspection period and preventive replacement threshold in the performance of technological operations of crop and determine the possible effect.

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Анотація

ПРАВИЛО ЗАМІН ЕЛЕМЕНТІВ ВІДПОВІДНО ДО СТАНУ ПРИ ПЕРІОДИЧНОМУ ДІАГНОСТУВАННІ З УРАХУВАННЯМ ПРИХОВАНОГО ЕТАПУ РОЗВИТКУ ДЕФЕКТІВ

Шевченко С. А.

Визначені імовірність відмови, імовірність превентивної заміни і залишковий ресурс елементів та втрати врожаю залежно від періоду діагностування, порогів превентивної і коригувальної замін, імовірнісних параметрів швидкості деградації елементів сільськогосподарських машин. Одержані залежності можуть використовуватися при оптимізації обслуговування машин відповідно до технічного стану.

Аннотация

ПРАВИЛО ЗАМЕН ЭЛЕМЕНТОВ ПО СОСТОЯНИЮ ПРИ ПЕРИОДИЧЕСКОМ ДИАГНОСТИРОВАНИИ С УЧЕТОМ СКРЫТОГО ЭТАПА РАЗВИТИЯ ДЕФЕКТОВ

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Определены вероятность отказа, вероятность превентивной замены и остаточный ресурс элементов и потери урожая в зависимости от периода диагностирования, порогов превентивной и корректирующей замен, вероятностных параметров скорости деградации элементов сельскохозяйственных машин. Полученные зависимости могут использоваться при оптимизации обслуживания машин по техническому состоянию.