Determination of conditions for frequency adjustment of maintenance (M) and routine repair (RR) of electrical equipment under risk-oriented strategy of technical operation

V.A. Trushkin[1,*], *S.V.* Schlyupikov[1], *O.N.* Churlyaeva[1], and *A.S.* Guzachev[2]

[1]Saratov State Agrarian University named after N.I. Vavilov, Department of Engineering Physics, Electrical Equipment and Electrotechnology, 410012 Saratov, Russia
[2]Interregional Institute of Supplementary Education, Department of Economics and Management, 410002 Saratov, Russia

Abstract. Currently, in order to ensure the required fault-proof level of technological processes in agricultural production, the following strategies among the main ones: afterfailure, planned systematic and a mixed electrical equipment maintenance and repair strategy. The pervasion of information technology in this segment was not widespread. Application of information technologies in conjunction with implementation of risk-oriented strategy is one of the promising directions of electrical equipment maintenance optimization, yet requires adaptation to sectoral characteristics of agricultural production. The article describes the problem of determining the optimal conditions for adjusting the frequency of maintenance and repair of electrical equipment on the basis of risk-oriented approach. To solve this problem, the equation of annual costs for maintenance and repair of electrical equipment was drawn up taking into account the parameter of its failure risk. The relationship between the change of relative risk and the service frequency was established; based on it, the ranges of frequency adjustment of maintenance and ongoing repair were determined.

1 Introduction

Maintenance of complex technical systems involving many electrified processes must be arranged in such a way as to minimize the amount of maintenance and routine repairs (M and RR), and therefore material and equipment costs, while maintaining high reliability of systems and minimizing process damage [1]. In addition, each planned suspension of the process can lead to product losses to various extent [2,3]. Existing standards for the maintenance of electrical equipment in agriculture mostly do not consider the problems of service frequency optimization [4], and therefore should be subject to adjustment. Frequency adjustment issues have been raised in studies, for example [6,71,15], but have generally considered damage and maintenance costs indicators, or estimates of current technical condition by control of established diagnostic parameters. The proposed approach, which

*Corresponding author: v.a.trushkin@mail.ru

takes into account the failure probability and the resulting damage indicators, allows this issue to be addressed comprehensively and introduces a risk indicator *R*. So, in the study [9], the aggregate estimate of these indicators made it possible to conclude that objects - in our case, electrical equipment with a high degree of risk, - need to be serviced more often than the ones with a low degree.

2 Materials and methods

The research used the analytical data presented in [4,5,6,7,8,9], as well as the provisions of the risk management theory and the theory of reliability [10,11,12,13,14]. The basis is the comparative method of research, which compares two electric motors with similar parameters and process characteristics, which are operating on similar technological processes. As part of this method, the following interrelations analyses were performed: annual costs for maintenance and routine repair of electrical equipment; relative costs and frequency of electrical equipment maintenance; relative risk and frequency of electrical equipment maintenance. Ultimately, the study of these interrelations allowed to form the hypothesis of adjusting the frequency of electrical equipment maintenance.

3 Results and discussion

For the application problem solving of the periodicity adjustment, let us consider two electric motors of the same brand and with the same process characteristics, which provide the realization of similar technological processes. Both electric motors (Z_1 and Z_2) also have the same price of annual operating costs C_{M}, which includes the cost of the electric motors themselves and the equipment of the maintenance base. To account for Damage, we will introduce a more detailed indicator - failure risk of electrical equipment *R*. With given input data we get the following expression:

$$C_1 = C_{M_1} + C_{RR_1} + R_1, \tag{1}$$

$$C_2 = C_{M_2} + C_{\mathrm{RR}_2} + R_2, \tag{2}$$

Where C_{M_1} and C_{M_2} — annual maintenance costs of electric motors, RUB; C_{TP_1} and C_{TP_2}— annual costs for their routine repair, RUB; R_1 and R_2 - failure risks of electric motors in the options compared, rub./year.

Let us introduce the assumption that the failure risk of one of the motors (R_2) is less and it is serviced with the standard frequency t_{M_s} and t_{RR_s}, then the risk $R_1 > R_2$.

The annual costs of M and RR in presented in the form

$$C_{\mathrm{M}_1} = C_{\mathrm{M}} n_1, \tag{3}$$

$$C_{\mathrm{M}_2} = C_{\mathrm{M}} n_2, \tag{4}$$

$$C_{\mathrm{RR}_1} = C_{\mathrm{RR}} \lambda_1, \tag{5}$$

$$C_{\mathrm{RR}_2} = C_{\mathrm{RR}} \lambda_2, \tag{6}$$

where C — the cost of one M, rub.; n_1, n_2 — amount of works determined by M frequency of the first and the second electric motor

$$n_1 = \frac{12}{t_1}, \tag{7}$$

$$n_2 = \frac{12}{t_2}, \tag{8}$$

12 — the number of months in the year; t_1 and t_2 – M frequency of the first and the second motor, months, $t_2 = t_{\mathrm{M}_s}$; C_{RR} — average annual cost of one repair, rub./year; λ_1 and λ_2 — the failure rate of the first and the second motor respectively, year^{-1}.

Failure rate of the second motor (λ_2):

$$\lambda_2 = \lambda_b, \tag{9}$$

where λ_b is the basic (structural) failure rate at the standard RR frequency, year^{-1}.
Condition of optimal service frequency for the first electric motor will be

$$C_1 < C_2. \tag{10}$$

By substituting expressions (1) and (2) in condition (10) and converting them considering expressions (3) — (6), we have determined the cost of one M:

$$C_{\mathrm{M}}(\frac{12}{t_{\mathrm{M}_s}} - \frac{12}{t_1}) < C_{\mathrm{RR}}(\lambda_1 - \lambda_b) + R_1 - R_2 \tag{11}$$

The M frequency shall be expressed through the service frequency, as well as the failure rate [15]:

$$v^{-x} = \frac{t_{\mathrm{M}a}}{t_{\mathrm{M}_s}} \approx \frac{\lambda_a}{\lambda_b} \approx \frac{n_a}{n_{\mathrm{pl}}}, \tag{12}$$

where x is the failure occurence rate, x = 0.7—1.2; t_{M_a} and t_{M_s} — actual and standard M frequencies, months; λ_a — actual failure rate, year^{-1}; n_a and n_{pl}— number of actual and planned services, year^{-1}.

By introducing indicators of service frequency estimation, we will present the relative operating costs of Z^* as follows:

$$C^* = \frac{a+bv^2+rv}{v}, \tag{13}$$

where a and b are cost change factors for M and RR; v is the maintenance frequency based on the level of operation,

$$v = \frac{t_1}{t_{\mathrm{M}_s}}; \tag{14}$$

r — the relative risk of electric motors failure in the first and second option,

$$r = \frac{R_1}{R_2}. \tag{15}$$

Let us show this dependency (Figure 1).

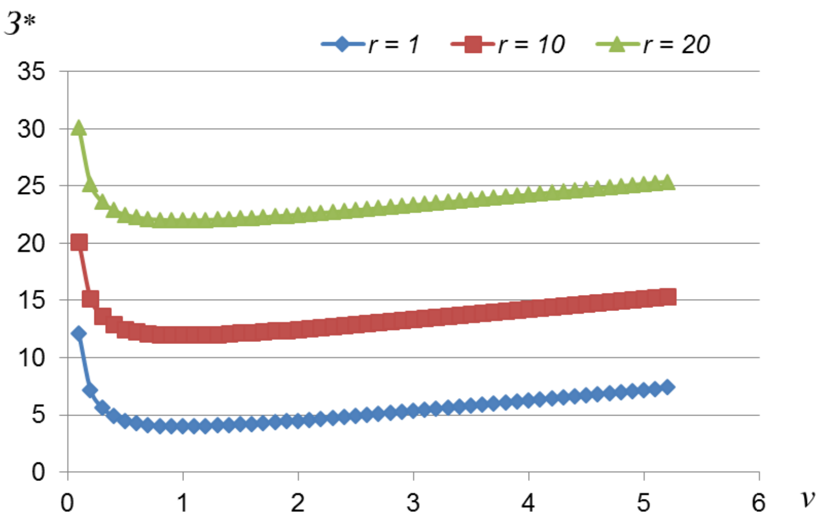

Fig. 1. Relative cost dependence C^*on maintenance frequency v of electric motor

Out of this figure it follows that the frequency of service increases with the relative risk increase. This dependence will take the following form:

$$r = \left|\frac{C^*\nu - a - b\nu^2}{\nu}\right| \tag{16}$$

We show this dependence in a way of a graphic (Figure 2)

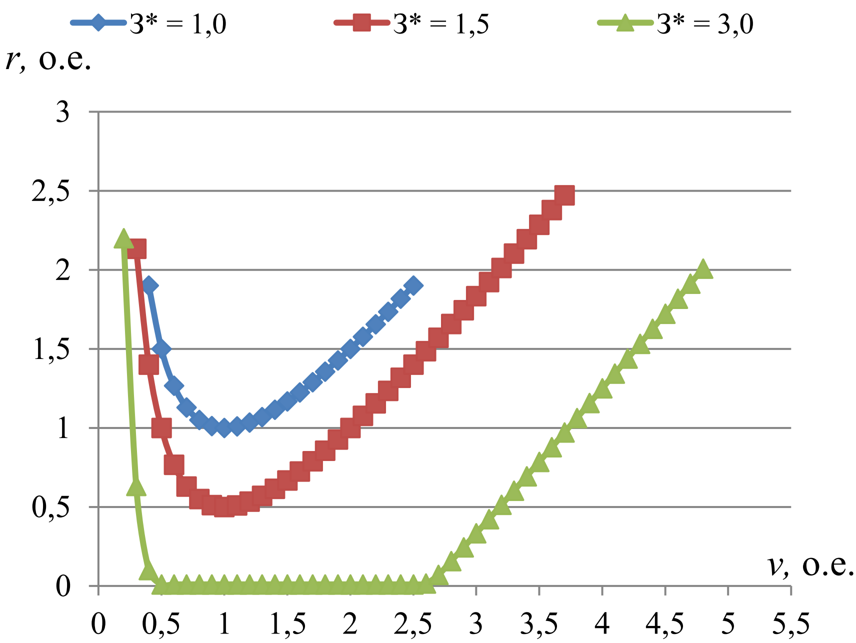

Fig. 2. Dependency in relation to risk r on maintenance frequency v of electric motor.

In the parabola extremum, the relative risk reaches minimum values. Provided that electrical equipment has high reliability indicators at relative costs C* = 1-1,5 r.u. (blue branch), then M and RR realize with a standard frequency ν = 1, then the risk *r* would be minimal, that is, no adjustment would be required. When the relative costs C* are increased by 3 times or more (green branch), the intersection points of the parabola appear on the abscise axis, which form the adjustment range of the standard frequency, at which the risk will be zero (*r* = 0). The lowest risk in such a case is achieved at the service frequency v from 0.5 to 2.5 r.u. This means that it is necessary to adjust the standard frequency in the range -36... +55%. Thus, according to this dependence, relative operating costs *C** and electrical equipment failure risk *r* shall be used for the optimal correction of M and RR frequency.

5 Conclusions

The specified theoretical justification of conditions of electrical equipment maintenance frequency adjustment on the basis of risk-oriented approach allows to transition to resource-saving operation; to spread the costs of the enterprise emphasizing the maintenance of "highly critical" electrical equipment, as well as to reduce downtime of technological processes due to M and RR. The next step in this study is to determine the optimal electrical equipment maintenance strategies based on the criticality degree of electrical equipment for the technological process realization.

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