Choosing a strategy for technical operation of electrical equipment

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Abstract. Electric motors are rechargeable products. The important point in the system of maintenance and repair of electric motors is the choice of optimal maintenance strategy. At present the most widespread is the planned preventive maintenance strategy. However, condition based maintenance is gaining in importance. In this paper, the choice of the most optimal maintenance strategy out of the above-mentioned strategies is considered. For this purpose, expressions have been developed to determine the total costs associated with these maintenance strategies for electric motors. Based on these expressions, a relationship was proposed to establish the optimal maintenance strategy. For the convenience of selection, a monogram was developed to reduce the time for selecting the optimum motor maintenance strategy.

1 Introduction

Electrical equipment, including electric motors, is classified as renewable (repairable). The technical condition parameters of electrical equipment are reduced as it is used for its intended purpose. Maintaining and restoration of technical condition parameters within permissible limits is ensured by carrying out technical maintenance and repairs. An important point in organisation of maintenance and repair system for electrical equipment is to find an optimal variant of its technical operation (maintenance) strategy. The strategy of technical operation determines the rules of technical maintenance, current and overhauls; labour intensity of these works; material and technical means and periodicity of some types of works [1,2].

The following strategies have emerged for the technical operation of electric motors in agricultural production: post-failure (zero failure), preventive maintenance and condition-based maintenance.

In a zero strategy, no maintenance or repairs are carried out, and the failed motor is replaced after it has failed. The use of this strategy leads to low reliability values, therefore it is rarely used [3].

With the preventive maintenance strategy, current and overhaul repairs are carried out regardless of the loss of motor availability. In the event of a failure, the motor is repaired and continues to run until the next repair. In this case, the motors are repaired with a long
residual life. It is known that unnecessary disassembly and reassembly of the motor is in itself an unnecessary material cost and accelerates the wear of the motor.

The most advanced strategy for operating electric motors is the condition-based maintenance strategy. This strategy leads to a significant reduction in the number of failures. However, it requires special, expensive diagnostic tools and competent specialists.

This work is devoted to selection of strategy of technical operation of electric motors of roof ventilation of agricultural enterprises, including poultry farms and cattle-breeding complexes, having in operation a considerable number of electric motors of the same type. This will be compared with a planned and preventative maintenance strategy and a condition-based maintenance strategy.

2 Research objective

To justify expressions for selecting the optimum motor maintenance strategy based on minimum annual costs.

The annual costs, in general terms, of operating electrical equipment, including electric motors, of agricultural enterprises can be represented as follows [4-6]. For the electric motors in question, these costs are as follows:

\[ H = I + U + K, \]  \hspace{1cm} (1)

where \( I \) is the annual cost of maintaining and restoring the service motors;
\( Y \) - damage due to failure of electric motors;
\( K \) is the annual capital cost of operating the electric motors.

Since, as a rule, the overhaul of electric motors is carried out at specialised or service organisations, the maintenance and restoration of the service electric motors will be carried out by the electrical service of the agricultural enterprise by means of maintenance and current repairs. Hence, these costs, \( Y_p \) and \( Y_c \), respectively, will be equal when the preventive and predictive strategy is used and the condition-based strategy is used:

\[ I_p = I_{pto} + I_{ptr}, \] \hspace{1cm} (2)
\[ I_c = I_{cto} + I_{ctr}, \] \hspace{1cm} (3)

In [7] the equality of \( I_{pto} = I_{cto} \) of the annual labour intensity of the given maintenance operations. This is due to a decrease in the number of maintenance operations in the condition-based maintenance strategy and, at the same time, an increase in this labour intensity due to the inclusion of operations related to the diagnosis of electric motors into the maintenance composition.

Annual economic loss due to electric motor failures using the planning and prevention strategy \( Y_p \) and the condition strategy \( Y_c \) is the cost of overhauls and repairs of \( Y_r \) of the motor that has failed and the resulting technological damage \( Y_t \). Hence, the costs of damage due to a single motor failure for both strategies are as follows:

\[ Y_1 = Y_{r1} + Y_{t1}, \] \hspace{1cm} (4)

where \( Y_{r1} \) – is the cost of overhauling the electric motor;
\( Y_{t1} \) - technological damage due to electric motor failure.

The annual costs of overhaul and technological damage for the respective strategies are:

\[ Y_{pr} = N \cdot Y_{r1} \cdot \lambda_p, \] \hspace{1cm} (5)
\[ Y_{cr} = N \cdot Y_{r1} \cdot \lambda_c, \] \hspace{1cm} (6)
\[ Y_{pt} = N \cdot T_{r1} \cdot \lambda_p, \quad (7) \]
\[ Y_{ct} = N \cdot T_{r1} \cdot \lambda_c, \quad (8) \]

where \( N \) - is the number of electric motors in question;
\( \lambda_p \) - motor failure rates under a planned and preventative maintenance strategy;
\( \lambda_c \) - the failure rate of electric motors under the condition-based maintenance strategy.

The application of a state-of-maintenance strategy reduces the number of failures per unit of time by identifying the pre-failure state and correcting it in time. The fraction of failure reduction is \( \rho \), hence the failure rate when using a stateful maintenance strategy will be equal:

\[ \lambda_c = \lambda_p (1 - \rho). \quad (9) \]

The annual capital costs of operating electrical equipment under a planned and preventative maintenance strategy \( K_p \) and the condition-based maintenance strategy \( K_c \) of the electric motors are equal:

\[ K_p = E \cdot K_b \quad (10) \]
\[ K_c = E \cdot K_b + K_\sigma \quad (11) \]

where \( K_p \) - is the capital investment in the motor maintenance and repair base;
\( K_\sigma \) - capital investment in motor diagnostics.

For comparison, the annual costs are \( C_p \) и \( C_c \), respectively, for maintenance of electric motors of the agricultural organisation at use of preventive maintenance strategy and strategy of maintenance according to the condition of these electric motors. For this purpose, let us represent formula (1) in the form of dependence (9):

\[ C_p = I_{ptr} + N\lambda_p \cdot (Y_{r1} + Y_{t1}) + EK_b \quad (12) \]
\[ C_c = I_{ctr} + N\lambda_p \cdot (1 - \rho) \cdot (Y_{r1} + Y_{t1}) + EK_b + EK_\sigma \quad (13) \]

Ensuring the availability of electric motors leads to a reduction in the failure rate and is associated with certain costs. In order to evaluate the investment projects it is necessary to calculate the integral indexes of available technical and economical information [4,5].

### 3 Research results

This paper targets investment in diagnostic tools for assessing the condition of electric motors. The main objective of this investment is to reduce the costs of maintenance by using the proposed condition-based maintenance strategy for electric motors. This requires that the annual total cost of using the condition-based maintenance strategy is less than the annual cost of using the preventive maintenance strategy:

\[ C_c < C_p. \quad (14) \]

After appropriate conversions, we establish the feasibility requirement for a condition-based maintenance strategy versus a planned preventive maintenance strategy for electric motors:

\[ \lambda_p \rho > \frac{I_{ctr} + I_{ptr} + EK_\sigma}{Y_{c} \cdot N}. \quad (15) \]
For ease of reference in expression (15), we denote the relative costs given in the right-hand side of expression (18) by $Z$:

$$Z = \frac{I_{ctr} - I_{ptr} + E K_\sigma}{Y_1 N}, \quad (16)$$

As an example, let's consider the choice of optimal strategy of technical operation of electric motors. At the agricultural enterprise, let's suppose on a poultry farm, electric motors of one standard size of roof ventilation in quantity $N=1000$ are operated, at change of planned - preventive strategy with intensity of failures $\lambda_p = 0.15 \text{ year}^{-1}$ to the strategy of condition-based maintenance the number of failures has fallen by 20% ($\rho=0.2$), cost of the set of diagnostics means $K_\sigma = 300$ thousand rubles, damage from electric motor failure $Y_1 = 4$ th. rub., costs for running repair of compared strategies are approximately equal $I_{ctr} \approx I_{ptr}$. Using expression (15), it is established, that $\lambda \cdot \rho = 0.03$ and $Z = 0.011$. Since $\lambda \cdot \rho > Z$, the optimum maintenance strategy is condition-based maintenance.

If $K_\sigma = 200$ thousand rubles, then under other equal conditions according to equation (15) $\lambda \rho = 0.03$ and $Z = 0.075$, i.e. condition of the equation is violated. In this case, it is advisable to use a planned and preventive maintenance strategy.

A graphical representation of the function (15), which provides a simple geometric operation to select the motor maintenance strategy, can be made using a monogram (Figure 1).

To use it, plot the failure rate on the abscissa and draw a perpendicular line. On the ordinate axis, plot the failure rate and draw a horizontal line. The intersection point will indicate the zone that corresponds to a preventive maintenance strategy and a condition-based maintenance strategy. The strategy found is useful for the maintenance of the electric motors in question.

![Fig. 1. Boundaries for the selection of maintenance strategies for electrical equipment; PP, preventive maintenance strategy; TS, condition-based maintenance strategy.](image)

For example, with relative costs $Z=0.02$, the intersection of lines corresponding to $\lambda_p = 0.13 \text{ year}^{-1}$ and $\rho=0.2$, is point A, so the maintenance strategy according to technical condition will be optimal. In the other case, if $Z=0.03$, under otherwise equal conditions it is advisable to use a planned - preventive maintenance strategy.
4 Conclusions

Based on the above it can be concluded that the expression (15) establishes a boundary of transition from the planned and preventive maintenance strategy to the strategy of condition-based maintenance. Thus the choice of strategy is influenced by the number of serviced objects, intensity of their failures, share of reduction of number of failures due to use of diagnostic means, expenses for current repairs, expenses for acquisition of diagnostic means, values of damage from electric motor failure.

References

5. S.V. Oskin, Methods and means to improve the operational reliability of asynchronous unregulated electric drives for feed mills and agricultural product processing enterprises (Ph. Chelyabinsk, 1998)