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PROCEDURE FOR SIMULATION OF STABLE THERMAL CONDUCTIVITY OF BEARING ASSEMBLIES

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Abstract:
The article developed a methodological basis for implementing automatic diagnostics based on thermal analysis of bearing assemblies. The diagnostic criteria of the technical operation condition and the procedure for determining the temperature ratio inside and outside the bearing unit based on the finite element analysis (FEA) of stable thermal conductivity have proven to be justified. Method of simulation of stable thermal conductivity of bearing units using KOMPAS-3D software and APM FEM finite element analysis module is proposed. The developed method was tested in practice and verified based on the results of theoretical and experimental studies. The developed method enables the determination of the relationship between the observed temperature on the surface of the bearing units and the friction temperature in the wear zone.

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1. INTRODUCTION

Data on the heat release of friction units can serve as an indicator of their technical condition and a combination of effective methods, techniques and technical means for diagnosing mechanical transmission units will provide increased reliability [1-5]. For bearing assemblies, measuring not the amount of heat released but the friction temperature in the wear zone is advisable. When diagnosing the bearing, the measured temperature is compared with the limit value of 250°C [6]. The use of automatic temperature control allows the use of two diagnostic criteria - friction temperature in the wear zone and the rate of change of friction temperature in the wear zone [7-10]. The speed of temperature change in the friction zone can be the most important technical indicator of the change in the working state of the bearing units. In the process of operation of agricultural machines with mechanical transmissions, the following modes of thermal loads of bearing units are observed: 1) establishment of stable temperature; 2) quasi-steady temperature rise; 3) temperature jump after establishing a stable temperature [11-13].

The first mode - is characterized by an increase in the temperature of the bearing assembly; the temperature growth rate is high at the beginning of its operation, at which and then the speed decreases. The temperature practically does not change, which is an indicator of the onset of heat balance - the amount of heat generated by the bearing is equal to the amount of heat discharged to the environment (Fig. 1). In this thermal load mode, the temperature does not reach the limit value, and a short-term jump is observed at the temperature growth rate, which is not an indicator of the critical state.

The quasi-steady temperature rise is characteristic of the normal operation mode, in which the rate of temperature change does not take critical values, and the temperature value can reach the limit value, for example, due to uniform mechanical wear. In this mode, the temperature is the diagnostic criterion (see Fig. 2).

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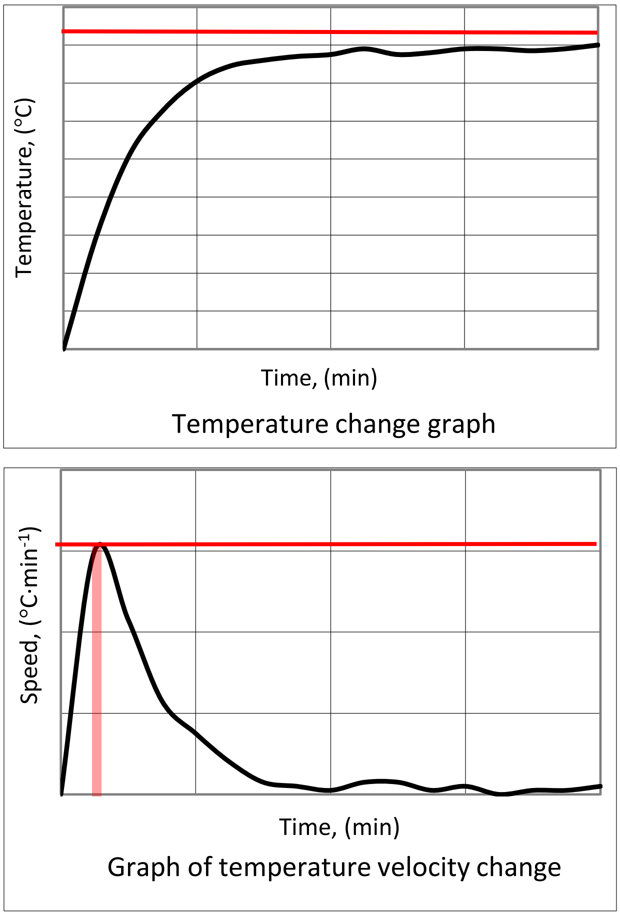

Fig. 1. Establishment of steady-state temperature

The third way of thermal load - is characterized by a temperature jump after establishing a stable temperature when reaching the limit state of the bearing assembly during mechanical wear, deterioration of lubrication conditions or emergency excess of permissible mechanical loads. In this case, the diagnostic criterion can be both the achievement of the limit temperature and the achievement of the limit rate of temperature growth (Fig. 3).

Thus, the use of automatic temperature control means of bearing assemblies should be based on the development of measuring equipment based on microcontrollers and software that allows measuring and comparing not only the temperature value but also the rate of its change [14-20]. It is necessary to develop an appropriate subroutine in the software algorithm to eliminate errors of the second kind when setting a stable temperature.

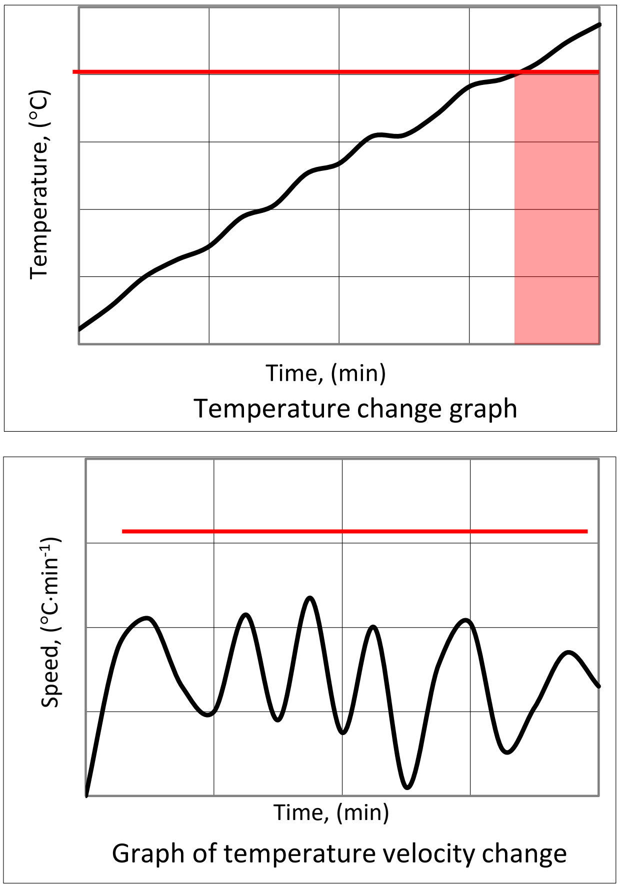

Fig. 2. Quasi-steady temperature rise

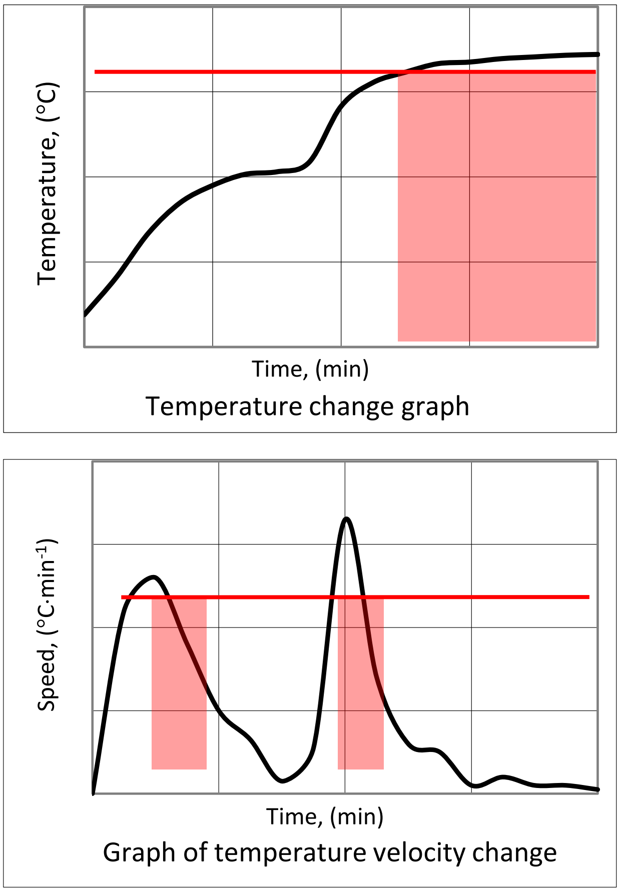

Fig. 3. Temperature jump after the establishment of stable temperature

To solve this problem, two methods are used: 1) calculation according to the heat balance equation; 2) FEA numerical method of stable thermal conductivity. Using special software, the second method is the most acceptable. This work presents the results of developing and implementing the methodology for modeling the stable thermal conductivity of bearing assemblies. The results of the procedure testing were confirmed by laboratory bench and operational tests.

2. MATERIALS AND METHODS

Currently, a large amount of software allows simulating physical processes. Our study uses KOMPAS-3D software (manufacturer: ZAO ASCON, Russia) with APM FEM finite element analysis module (Scientific & Technical Center “APM”, Russian Federation). This module is limited to stable calculations only for thermal conductivity, sufficient for diagnostics bearings since the technical condition is monitored at the steady-state operation mode when a thermal balance with the environment occurs. A significant limitation in using the module is the impossibility of considering convective heat exchange with the environment.

Study objects - bearing assemblies on mechanical gears used in transmissions of transport and process machines.

Loading modes of bearing units are determined based on kinematic schemes of transmissions and nominal and maximum power flows.

Digital thermometers, pyrometer and thermal camera carried out temperature measurements during tests.

3. RESULTS AND DISCUSSION

Based on the conducted theoretical and experimental research, the dependencies between the friction temperature in the wear zone and the temperature on the surface of bearing units were determined based on the method of modeling stable thermal conductivity (Table 1).

The convergence between the theoretical and experimental temperature values in the friction zone proves the method’s practical validity (applicability).

Table 1. Results of application on the method of modeling stable thermal conductivity

Object	Theoretical temperature, °C	Experimental temperature, °C	Difference, %
Cardan joint K 040	84.9	106.0	19.9
Cardan joint K 100	139.0	133.0	4.3
Cardan joint Walterscheid 2200	169.8	116.0	31.7
Cardan joint Eurocardan Size 5	161.3	163.0	1.0
Bearing 6203-2RS Timken	97.4	78.0	19.9
Bearing 50412	45.0	52.9	14.9
Bearing 53610	49.8	56.1	11.2

When establishing the connection between the temperature in the measurement zone and the friction temperature in the wear zone, the linear nature of the relationship was discovered, which is called - the coefficient of proportionality of the finite element model, Eq. 1:

$$k = \frac{(\Theta_D - \Theta_0)}{\Theta_F}, \quad (1)$$

where are:

- ✓ k - coefficient of proportionality of finite element model;
- ✓ Θ_D - the diagnostic operating friction temperature in the wear zone, °*C*;
- ✓ Θ_0 - ambient temperature, °*C*;
- ✓ Θ_F - friction temperature in the wear zone, °*C*.

Using this factor, it is possible to calculate the friction temperature in the wear zone from the results of measurements of temperature in the measurement zone and air temperature.

Based on the research, recommendations were developed for creating three-dimensional models, applying temperature loads and analyzing the results obtained.

The following rules must be followed when creating the model of the node under investigation:

1) maximum simplification of design, removal of insignificant structural elements of parts (chamfers, rounds, grooves, grooves etc.) to reduce the calculation time using the FEA method;

2) the mass of parts adjacent to the tested bearing should exceed its mass by 3-4 times to

increase the accuracy of calculating the coefficient *k*;

3) all assembly parts must be assigned the appropriate material.

Application of temperature loads shall be carried out in the following order:

1) the value of the friction temperature in the wear zone to load the rolling bodies of the bearing (s);

2) surfaces, through which heat is transferred to the environment, are loaded with temperature 0°C;

3) do not load two types of surfaces with temperature: inside the body parts and the surface/zone for thermal measurement.

In this case, the structure diagram of the finite element model (FEM) will be as follows (Fig. 4).

After dividing the model into a finite element grid and performing the calculation, the next step is to analyze the results. In doing so, do the following:

1) in the temperature measurement zone, obtain several values at different points with the calculation of the average value;

2) repeat the analysis for several temperature values in the friction zone;

3) based on the analysis results' approximation, calculate the FEM – *k* coefficient.

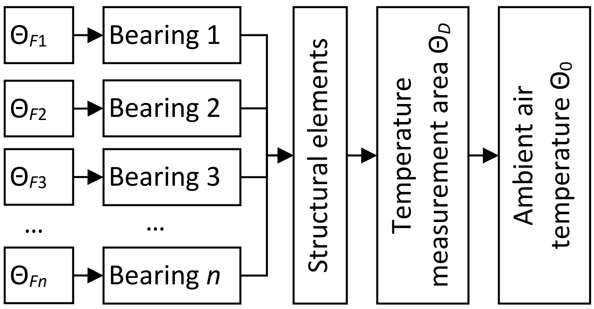

Fig. 4. Block diagram of a finite element model

Fig. 5 shows an example of a FEM of a bearing assembly made considering the developed recommendations.

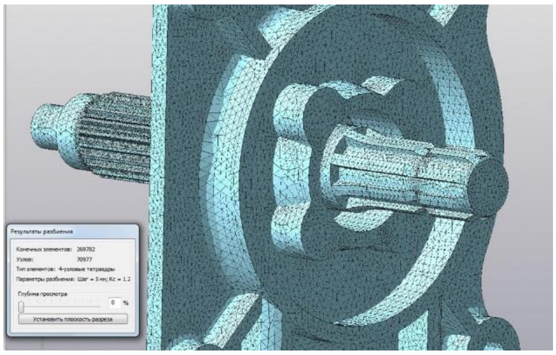

Fig. 5. Finite element model

This example shows a model of the bearing assembly of the power takeoff shaft gearbox of Belarus - 82.1 tractor. In addition to the bearing, the model includes a shaft and a fragment of the gearbox housing. Bearing balls are loaded with temperature in friction zone, outer surfaces are loaded with a temperature of 0°C, and inner surfaces and temperature measuring zone (outer surface of reduction gear housing around bearing) are not loaded.

Fig. 6 shows the map of temperature fields - the result of finite element analysis.

As recommended, the Leader tool determines the temperature at multiple points (less than ten points) in the temperature area. The average values of the diagnostic operating temperature at the preset friction temperature in the wear zone are calculated based on the measured values.

Then, the friction temperature in the wear zone is changed in the model, and the finite elements are divided into a grid and calculated. Using the obtained new map of temperature fields value of the diagnostic operating temperature is calculated.

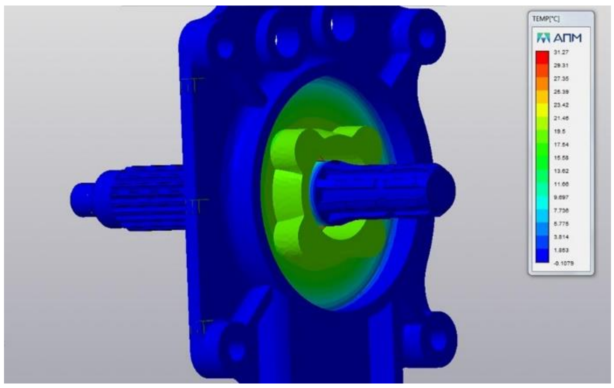

Fig. 6. Map of temperature field

Based on the results of the analysis of different friction temperatures in the wear zone, Fig. 7 shows the diagram of the diagnostic operating temperature in relation to the temperature of the friction zone.

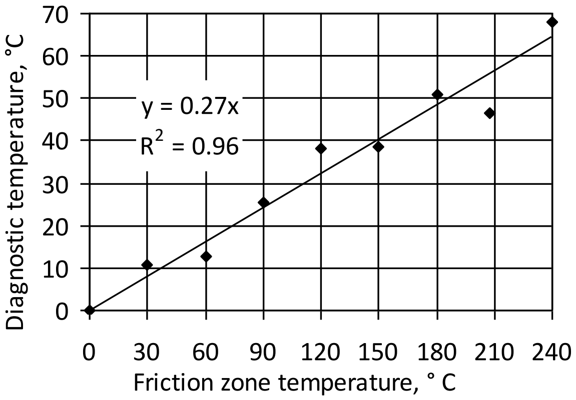

Fig. 7. Diagram of diagnostic operating temperature versus friction zone temperature

In this example, the coefficient of the trend line equation is 0.27 and is the desired coefficient of proportionality of the FEM - *k*.

4. CONCLUSION

The most important results of the conducted research were:

1. The developed and presented method of simulating the stable thermal conductivity of bearing units is necessary for their diagnostics and applies to the automatic monitoring of technical conditions.

2. Based on the research results, recommendations were developed for creating three-dimensional models, applying temperature loads and analyzing the results obtained to determine the proportionality coefficient of finite element models.

3. It is recommended that further research consider possible heat exchange with the environment with the help of software.

4. Perspectives for improving the technology of technical diagnostics regarding the digitalization of the process for evaluating the friction temperature in the wear zone should be based on developing an electronic control system for mechanical transmissions on agricultural equipment.

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