Thermal diagnostics of mechanical gear elements of combine harvester

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Abstract. The work carried out practical testing of the technology of thermal diagnostics of belt gear elements of the grating mill drive of the combine harvester. The basis of the technology is the principle of using the coefficient of the temperature ratio on the surface of the diagnosed unit and temperature in the friction zone, expressed through the coefficient of proportionality of the finite element model. The peculiarity of the thermal diagnostics, in this case, is to compare the temperature in the friction zone with the maximum allowable temperature for the direct contact zone in the mechanical transmission unit. The object of the study is the tensioning roller of the drive of the grating mill of the first stage of the CLAAS TUCANO 580 combine harvester with 6203-2RS TIMKEN bearings. The result of the numerical experiment showed a significant effect on the temperature in the friction zone of the operational parameters - radial force and rotational speed. The use of 3D-modeling made it possible to determine the key parameter of the proposed thermal diagnostics technology - the proportionality coefficient of the finite-element model $k=0.489$. The temperature of the bearing assembly of the tension roller was measured periodically, using a non-contact method during harvesting in the 2020 season. For the period of regular observations of 128 moto-hours, the value of the maximum temperature growth rate in the friction zone $V_τ=0.025$ °C/min and the maximum temperature in the friction zone 69.5 °C, taking into account the ambient air temperature, were determined. No failures of the diagnosed unit were found. In the process of application of thermal diagnostics technology, no errors of the first kind are recorded, which indicates the effectiveness of the proposed technology.

1. Introduction

An analysis of the state of production and prospects for the development of the agricultural engineering industry of Russian enterprises showed that in 2020 the production of four-wheel drive agricultural tractors and agricultural machines increased significantly by about 30% to 149 billion rubles, while the export of Russian agricultural equipment to the Commonwealth of Independent States countries, Africa, the Middle East and the European Union increased by 30% and reached almost 16 billion rubles. This fact is explained by the favorable and attractive «price/quality» ratio. In this regard, the issues of increasing the competitiveness of domestic agricultural equipment set forth in the federal scientific and technical program for the development of agriculture in the Russian Federation for the period of 2017-2025 determine the scientific justification of technologies and technical means of diagnosing mechanical transmissions as systems that limit the reliability of
A promising direction of diagnostic technology is the development of built-in (on-board) and express diagnostics. Systems such as engine, electrical equipment, hydrodynamic transmission of modern agricultural machinery are partially or completely covered by means of built-in automatic diagnostics, but for the diagnosis of mechanical transmissions such means and technologies are not available. The most effective and applicable method in this case is thermometric diagnostics, in which, according to the parameters of the thermal load of friction pairs, their technical condition can be estimated [2-4].

In the presented work experimental testing of thermometric nondestructive testing of mechanical transmission units is carried out using the example of the bearing unit of the belt tensioner pulley drive of the grating mill of the CLAAS TUCANO 580 grain harvester.

2. Materials and methods

Implementation of thermal diagnostics of mechanical transmission elements consists in determination of temperature in friction zone on the basis of diagnostic (actual) temperature and its comparison in friction zone with maximum permissible value on the basis of equation [5, 6]:

\[ \Theta_F = \frac{\Theta_D - \Theta_0}{k} < \Theta_L, \]  

where:  
- \( \Theta_F \) – temperature in the friction zone, °C;  
- \( \Theta_D \) – diagnostic temperature, °C;  
- \( \Theta_0 \) – ambient temperature, °C;  
- \( \Theta_L \) – temperature limit, °C;  
- \( k \) – coefficient of proportionality of the finite-element model.

Measurement of the diagnostic temperature \( \Theta_D \) was performed using the INSTRUMUMAX PIRO-330 infrared pyrometer. The distance of contact - free measurement of bearing cover surface temperature in the area of 15 mm diameter was 180 mm.

The coefficient of proportionality of finite-element model was determined on the basis of modeling of temperature fields in a zone of the bearing unit of the belt tensioner pulley drive (Figure 1) by the finite element method in CAD KOMPAS-3D V18 with use of the APM FEM application.

**Figure 1.** Drive of the grating mill of the combine harvester CLAAS TUCANO 580:  
* a – kinematic diagram of drive circuit; b – measurement of unit temperature.

The object of the investigation is the tensioning roller of the drive of the grating mill of the first stage of the combine harvester CLAAS TUCANO 580 with bearings 6203-2RS TIMKEN.

Figure 1,a shows the kinematic diagram of the drive loop of the grating mill of the CLAAS TUCANO 580 combine harvester to determine the loading parameters of the tensioning roller bearings. As the loading parameters of the bearing 6203-2RS Timken, we take the range of values
0...5000 H for radial force and 0...104.7 s$^{-1}$ for the angular velocity. Figure 1.b shows the process of measuring the temperature of the bearings of the tensioning rollers of the drive of the grating mill of the CLAAS TUCANO 580 combine harvester with the infrared pyrometer INSTRUMAX PIRO-330.

### 3. Results and discussion

A mathematical model describing the dependence of temperature in the bearing assembly zone on structural, technological and operational factors has [5, 6]:

$$\Theta_F = \frac{\delta F \omega}{2hl \left( \lambda \sqrt{\frac{2 \alpha (h + \pi r)}{\lambda \pi r}} + k' \rho c \cdot 2.6 \sqrt{\frac{a \omega r}{\lambda D}} \right)},$$

where

- $F$ – bearing load, N;
- $h$ – length of spike, m;
- $r$ – radius of spike, m;
- $\omega$ – angular speed, s$^{-1}$;
- $f$ – friction coefficient;
- $I$ – mechanical equivalent of heat;
- $\lambda$ – thermal conductivity, W·m$^{-2}$·ºC$^{-1}$;
- $k'$ – coefficient of proportionality;
- $\rho$ – material density kg·m$^{-3}$;
- $c$ – specific heat, J·kg$^{-1}$·ºC$^{-1}$;
- $a$ – thermal diffusivity, m$^2$·s$^{-1}$;
- $\lambda_D$ – wavelength of irregularities on the wear surface, m.

In order to calculate the quantitative influence of the analysed factors on temperature growth in the friction zone, a numerical experiment was carried out on the basis of formula (2) with radial loading on the bearing $F=0...5000$ H and angular velocity $\omega=0...104.7$ s$^{-1}$. A graphical interpretation of the results of the numerical experiment is shown in Figure 2.

The analysis of the presented dependence (Figure 2) indicates a significant effect of loading factors on the level of heat generation of bearing assemblies. The radial force and angular velocity can vary rapidly when adjusted by the combine operator, and also change when harvesting different crops of different yields. Therefore, the temperature in the friction zone must be monitored continuously.

To determine the proportionality factor of the finite element model, a 3D-model of a tension roller with a bearing assembly is created, which is presented in Figure 3 [7]. For a given 3D-model, under the described loading conditions, the diagnostic temperature was $\Theta_D=25$ ºC at a friction zone temperature of $\Theta_F=53.1$ ºC. By varying the value of the temperature $\Theta_D$ for the finite element model, the value of the proportionality coefficient of the finite element model is $k=0.489$ (Figure 4).

Results of operational observations of diagnostic temperature of bearings 6203-2RS Timken $\Theta_D'$ are presented in the unit in Figure 5. Here skilled points $\bullet$ are designated; 1 - characterize change of diagnostic temperature, and reference points $\blacktriangle$ are designated; 2 - characterize temperature in a friction zone which is determined taking into account coefficient of proportionality of final and element model $k=0.489$ by formula (1). Since the bearing was located under the closed hood of the left side of the combine, solar radiation did not affect its thermal balance, which is indirectly confirmed by the value of the approximation coefficient $R^2=0.82$.

During the period of operational observations of 128 moto-hours, the maximum temperature change rate was $V=0.025$ ºC·min$^{-1}$, and the temperature in the friction zone did not exceed 69.5 ºC. No failures of the diagnosed unit were detected.

The performance tests made it possible to test the method of thermal diagnostics on the basis of mathematical models of heat generation according to two diagnostic parameters - maximum temperature in the friction zone and maximum rate of temperature change.
Figure 2. Temperature in the friction zone depends on the radial force and angular velocity.

Figure 3. Temperature field map of the bearing unit 6203-2RS Timken.
Figure 4. The dependence of the diagnostic temperature on the temperature in the friction zone.

Figure 5. Results of temperature measurement and calculation of the bearing 6203-2RS Timken.

Similar results were obtained by researchers during bench and full-scale tests of friction units taking into account the angular speed of the shaft to increase the accuracy and the information value of diagnostics of the technical state of friction units of machines [8] taking into account the improvement of the metrological support of measurements of parameters of the technical state assessment [9] to optimize parameters of structural elements of machine parts [10].

4. Conclusion
A summary of the above results provides the following conclusions:

− based on the system approach, thermometric nondestructive testing technology for diagnostics of mechanical transmission elements is justified and implemented;
− result of the numerical experiment showed a significant influence of radial force and angular velocity on the temperature in the friction zone of the operational parameters of loading;
− key parameter of proposed thermal diagnostics technology is defined - proportionality coefficient of the finite-element model \( k = 0.489 \);
operational testing of the thermal diagnostics technology made it possible to determine the maximum values of the temperature growth rate in the friction zone \( V = 0.025 \, ^\circ \text{C} \cdot \text{min}^{-1} \) and the temperature in the friction zone 69.5 °C against the background of the absence of failures of the diagnosed unit.

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