THERMAL IMAGING STUDIES ON GRAIN HARVESTER BELT TRANSMISSIONS

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Abstract

The purpose of this research was to determine the conditions for cooperation amongst various components of belt transmission systems in grain harvesters in terms of thermal loads acting on them under operational conditions. A number of field research tests were conducted, using the thermal image measurement method, where selected structural elements of the belt transmission systems were depicted with a thermal imaging technique. The authors focussed on the methodological benefits and problems resulting from the research manner adopted. The authors presented results which could provide a valuable source of information of a utilitarian nature as they could be used for diagnosing the technical condition of kinematic nodes in the mechanical transmission systems in question.

Key words: grain harvester, belt transmission systems, working temperature, thermal imaging studies.

BADANIA TERMOWIZYJNE PRZEKŁADNI PASOWYCH KOMBAJNÓW ZBOŻOWYCH

Streszczenie

Celem badań było określenie warunków współpracy elementów przekładni pasowych kombajnów zbożowych, w aspekcie ich obciążeń termicznych generowanych wymuszeniami eksploatacyjnymi. Przeprowadzono szereg badań terenowych z zastosowaniem metody pomiaru termowizyjnego, w których dokonywano obrazowania termowizyjnego wybranych elementów konstrukcyjnych przekładni pasowych. W opracowaniu zwrócono uwagę na zalety i problemy metodyczne wynikające z przyjętego sposobu realizacji badań. Przedstawiono wyniki, które mogą stanowić cenne informacje o charakterze utylitarnym, ze względu na możliwość ich wykorzystania w procesie diagnostyki stanu technicznego węzłów kinematycznych analizowanych przekładni mechanicznych.

Słowa kluczowe: kombajn zbożowy, przekładnie pasowe, temperatura pracy, badania termowizyjne.

1. INTRODUCTION

Mechanical transmissions equipped with belt tension members are quite well recognized, both theoretically and practically. As emphasized in the subject literature [2, 17], their performance greatly depends on the maintenance of the correct relation between the torque transmitted and the friction force occurring between the belt and the pulley. Therefore, in engineering practice, i.e. in the design, construction and operating processes, the priority is given to minimizing slippage between the coping elements in the given belt transmission system in order to achieve their theoretical performance rate, estimated as 97%. In this respect, scientific and technical developments manifest themselves, inter alia, by the creation of software tools that support the belt transmission system design process [7, 9]. This also refers to technical solutions, such as, for instance, „Gemex" described by Szlachetko and Paulsson [14], which is used for the regulation of belt tension, with the simultaneous elimination of static flexure in the shafts the belt pulleys are mounted on. This reduces the slippage risk and helps the belt pulleys to work in a co-planary position, thanks to which the overload slippage risk, which is believed to be the reason for premature wear off of the belts and the belt pulleys, is reduced to a minimum [6].

The process of the structural development of belt transmission systems has undoubtedly contributed to their popularization in many technical applications. Nevertheless, as far as agricultural engineering is concerned, they do not belong to those which dominate the machine and equipment kinematic node technology. However, due to certain advantages, they are omnipresent in grain harvesters. These advantages include their simple structure, smooth and quiet work, damping vibrations and soothing loads, and the possibility to transfer torque to significant distances, which, with the considerable sizes of the harvesters and dislocation of their main working units, represent particular values. Nevertheless, the adoption of such a solution for transferring torque is not without problems. Large static loads, acting on the shafts and bearing nodes, carry the risk of damage and thus affect the reliability of the entire machine. Moreover, slippage of the belts on the pulleys which are typical of such transmission systems causes a buildup of heat in the friction-matching elements. In extreme cases, due to, for instance, work overload, bearing seizure or insufficient tension of v-belts, a fire hazard may emerge [13].

In their studies, the authors found it interesting to determine what thermal loads the grain harvester belt transmission systems are subject to under real operating conditions. In order to determine absolute values of temperature and their distribution over the surfaces of coping elements, the authors used a thermal camera. They also intended to verify the usability of the thermal image measurement in diagnosing the condition of the bearing nodes installed in the belt transmissions in the study.

These studies will be continued during subsequent agricultural periods of grain harvesting in order to gather more data from the same objects of measurement. The present stage of the study may be taken as a starting point in the search for answers to the following, still open, questions: within which temperature limits does the given belt transmission system work correctly, to what degree may the working temperature of the different components in the transmission system result in their wear and tear, and what absolute temperature values should entail the necessity to exchange the bearing nodes?

Although the idea to use thermal imaging technology in the diagnostics of kinematic nodes, especially the bearing nodes, is certainly not new, the absence of its application in testing belt transmission systems in grain harvesters is noticeable. At present, standard procedure in maintenance works on the transmission systems in question seems to be that users follow the service recommendations. Unfortunately, these are basically taken at pre-defined time intervals or upon the emergence of a malfunction. The authors' intention was to identify an alternative approach to maintenance of the systems, based on the evaluation of their actual technical condition. The studies started by the authors set the direction for a discussion on the possibility of diagnosing the technical condition of the transmission systems in question, using thermal-imaging measurements (or perhaps simpler and cheaper pyrometric tests).

2. METHODOLOGY OF THE EXPERIMENTAL WORK

2.1. Thermal imaging in the context of its pros and cons for measuring

In their research methodology, the authors resolved that thermal loads acting on the belt transmission elements would be measured with a Hotfind-Lxt thermal camera, selected technical characteristics of which are presented in Table 1. At present, the popularity of the thermal image measurement technique is noticeable [1, 4, 5, 8, 15] in many applications: industry, commerce and pure science. This is also true for the agricultural and food industries, where attempts have been made to use thermal imaging in the detection of the fungal contamination of grains [3], or to assess damage caused to fruit or vegetables [16]. On the other hand, the fact of the insignificant utilization of thermal imaging (in view of the potential applications) in diagnosing the technical condition of kinematic nodes in agricultural machines and equipment is observed.

Table 1.
Technical parameters of thermal camera HotFind-LXT

Parameter	Value	Parameter	Value
Resolution	384 x 288	Accuracy of measurement	± 2 K, ±2%
Thermal sensitivity	80 mK for 303 K	Measurement range	253 ÷ 1773 K
Spectral range	8-14 μm	Working temperature	253 ÷ 323 K

For thermal cameras, objects emitting infrared radiation or those with temperatures higher than absolute zero are measurable. The certainty of such measurements depends on a number of factors, including differences in the intensity of the measured signal generated by objects remaining within the camera range. From a technical point of view, the bigger the differences between the temperatures of the object of study and the surrounding objects (the background), the easier the interpretation of the thermal image is. Moreover, the measurement certainty is affected by emissivity ε, representing the relation between the density of the energy stream generated by the object in the study e, and the density of the energy stream generated by a perfect radiator e_c, with the same temperature:

$$\varepsilon = \frac{e}{e_c} \quad , \ (0 \leq \varepsilon \leq 1) \tag{1}$$

The emissivity of solid bodies departs - sometimes quite significantly - from the theoretical model of the perfect radiator as described with the Stefan-Boltzmann law:

$$e_c = \sigma T^4 \quad [\mathrm{W \cdot m^{-2}}] \tag{2}$$

where: $\sigma = 5.67 \cdot 10^{-8}\ \mathrm{W \cdot m^{-2} \cdot K^{-4}}$

In thermal cameras, designed for recording absolute temperature values, a computational algorithm, based on the above mentioned dependencies, is used. Therefore, the accuracy of the readings depends on the correct settings that take the actual emissivity of the given object into account.

In thermographic measurements, the imaging of objects with equal or similar emissivity, and at the same time close to the theoretical maximum ε=1 , is taken as favorable. This reduces the risk of error in the interpretation of the thermal images and the impact of the background on the measurement result – the surfaces of solid bodies, manifesting a high reflexivity (low values of ε), are difficult to measure due to the significant presence of reflected radiation in the measuring signal. In studies conducted in open spaces, attention is also drawn to the fact that it is preferable to conduct them when the sky is rather cloudy [10-12]. This will reduce the effect of the objects becoming heated due to solar radiation, as well as the radiation cooling effect. Moreover, it eliminates the risk of damage to the thermal camera as a result of directing the lens towards the sun disc. This risk results from the very high intensity of the radiation stream generated by the sun, comparing to the sensitivity of the detectors installed in the cameras – currently, bolometric detectors are predominant, which was also the case with the camera used in our own research.

2.2. Course of the Research

For obvious reasons, the optimal conditions for the thermal measurement of objects remaining in an open space are not the most desirable for the grain harvesting process. Despite the methodological difficulties mentioned above, the experimental studies were conducted in the atmospheric conditions typical of the actual process of grain harvester operation. The results obtained this way are a result of the mechanical loads transferred by the harvester working components, as well as the thermal effect determined by the adjacent thermal conditions. Nevertheless, it was ascertained that for the belt transmission systems in question, the conditions required for their good thermal measurability could be fulfilled; in particular, regarding the analysis of the temperature spread over the surfaces of the elements concerned (the high sensitivity of the thermal camera, equal to 0.08 K), as the materials of the v-belts and the paint coatings show high emissivity. Based on catalogue data and our own measurements, an emissivity coefficient value of ε = 0.95 was adopted to determine the absolute temperature values and analyze temperature distribution on the thermal images.

This research method also featured some other practical values such as, for instance, the rapid and contact-less recording of results, without having to stop the activity of the working teams, the possibility to record thermal images of the whole transmission unit and performance of the measurements in field conditions, with the option of analyzing and processing the data using some supportive computer software.

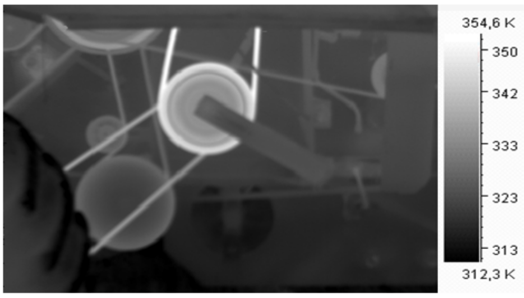
Previous experimental studies were conducted during the harvest seasons of 2013 and 2014 in the West Pomeranian Province, mainly in the commune of Pyrzyce. 37 harvesters of the following makes were tested: Bizon (6 machines), New Holland (5 machines), Massey Ferguson (2 machines), Claas (17 machines) and John Deere (7 machines). For the sake of safety, as well as to avoid disturbing the grain gathering process, the thermographic documentation of the belt transmission performance was prepared during the unloading of the grain from the harvesters to vehicles. Items "visible to the camera lens", such as belt pulleys, tensioning rolls and v-belts, were evaluated.

3. RESULTS OF THE STUDY

Drawings 1-5 present the results of thermal imaging for elements of the transmission systems in the selected grain harvesters. In Bizon ZO56 harvesters, the highest working temperature was observed in the variable-speed transmission of the motion drive (Fig. 1). For that transmission, the maximal recorded working temperature exceeded 365 K. This result was obtained on the v-belt, under a clear sky, with an adjacent temperature of more than 303 K. For measurements conducted at lower temperatures, on cloudy days (no exposure to the sun), temperatures of the transmission in question were lower by about 10 K. Based on the results achieved, it can be assumed that the temperature range of 353–365 K represents conditions conductive for the good performance of the given transmission system. This conclusion can be drawn from an analysis of the thermographs, based on which the absolute temperature values remaining within this range were determined. In total, 20 thermographs of the transmission system in question were analyzed, all made for the 6 Bizon harvesters during their operation under different load conditions. The variability of the operating conditions can be attributed to the fact that the thermographs were recorded at different times of day (changes in the background temperature) and that different crops (rape, wheat, barley) were harvested. The temperature range given above is far from the potentially extreme value. According to our own observations, confirmed by the experience of the Bizon ZO56 harvester users, in emergency situations an increase in the working temperature of the driving system transmission generates a fire hazard. At this point it needs to be noted that this structural weakness in the propelling system has been eliminated in the grain harvesters of the newer generations by using a hydraulic drive.

The temperature of 365.3 K, observed on the v-belt in the driving gear of the Bizon ZO56 harvester, was the maximum temperature in all the components of the belt transmission systems tested. For the other makes of grain harvester, their thermographs showed lower temperatures which, for the most loaded v-belt transmissions, remained most frequently within the 323–348 K range.

a)

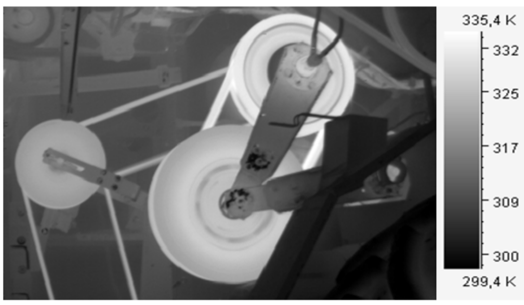


b)

Fig. 1. Thermographs of a Bizon Z054 grain harvester: a – view from the right, b – belt pulley of variable-speed transmission of the propelling system

The thermograph analysis indicates that where the power wheel in a belt transmission system works correctly, temperature gain results from the friction-based cooperation between the belt and belt pulley. In such circumstances, the pulley/v-belt combinations present the highest temperatures in the very belts and pulley rims, as for example, in Massey Ferguson transmissions shown in Fig. 2.

a)



b)

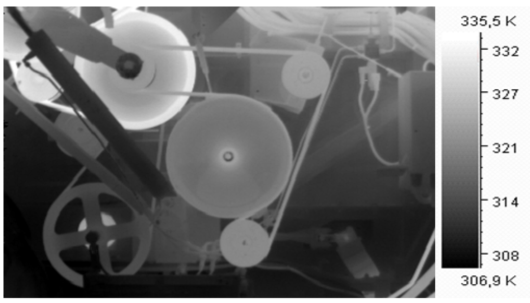
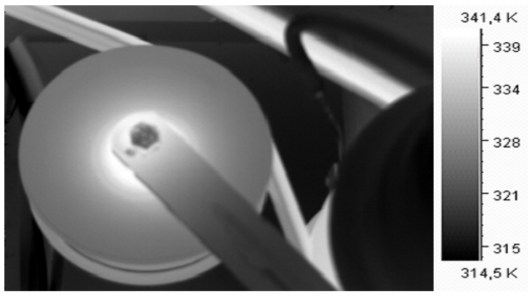


Fig. 2. Thermographs of belt transmissions: a - Massey Ferguson 7256, b - Massey Ferguson 36

For v-belt tensioners, most of the thermographs recorded show a uniform distribution of heat on their surfaces, which can be taken as a condition typical of their correct performance (Fig. 3b). However, the situation where the highest temperatures of the components concerned occur in their central areas may be evidence of deterioration in the bearing nodes. In order to document this notion, the authors compared thermographs of belt transmission tensioning rolls installed in New Holland TC 5080 harvesters (Fig. 3). The thermograph shown in Fig. 3a indicates a clear local increase of temperature in a belt tensioner roll within the area of a bearing node (T_{max} = 341.4 K). The occurrence of similar dependencies was identified for the pulleys playing the role of tensioning elements. Hence, it can be assumed that the temperature of the central areas of the tensioning rolls and pulleys may reflect the technical condition of the bearings, thus providing some information of a diagnostic nature.

a)



b)

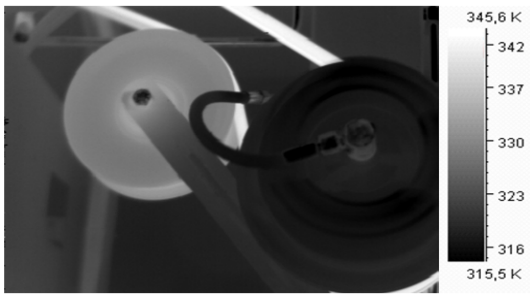


Fig. 3. Thermographs of tensioning rolls: a – New Holland TC 5080 (T_{max} = 341.4 K, representing the temperature of the central section of the roll), b – New Holland TC 5080 (T_{max} = 345.6 K, representing the temperature of the v-belt)

Figs. 4a-b present thermographs of the pulleys that tighten the belts on a selected transmission in the John Deere 1450. The cases studied herein indicate both a diagnostic value of the measurement and a possibility to draw conclusions regarding heat loads acting on the transmission system components, with various settings of the camera towards the object of the study. The maximum temperature values of 347.3 K and 347.4 K (Figures 4a and 4b, respectively) were recorded for the hub of the pulley, located on the right side of the thermographs. In Fig. 4a, the thermograph also presents a profile temperature distribution for the pulleys, permitting a quantitative assessment of the temperature variability along line L_1. The temperature analysis presented herein delivers some objective information on the performance of the bearing nodes, which, in the case of a quantitative (visual) assessment, based on the variability of the color palette in areas of different temperatures, can be misleading.

The v-belt transmission system is one, but not the only, engineering solution for belt transmission systems used in grain harvesters. The thermovisual research also covered cogbelt transmissions, which are used, for instance, in the driving system on Claas Lexion 760 harvesters (Fig. 5).

a)
b)

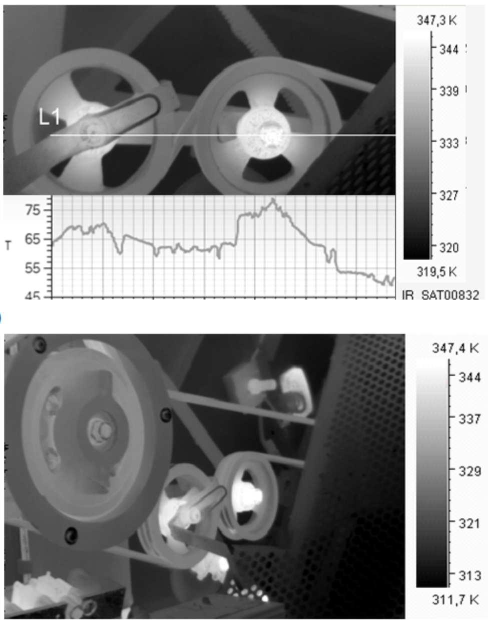


Fig. 4. Thermographs of tensioner pulleys, selected transmission in John Deere 1450: a – perpendicular position of the camera, b – camera positioned at an angle to the object, L_1 – line of reference for determining the temperature characteristics T

The maximum absolute working temperature values recorded in the components of the transmission in question exceeded 353 K. No differences were found in temperature distribution over the pulleys that might indicate the poor condition of the bearing nodes. It is worth mentioning, however, that the harvesters in the study (8 vehicles) were at that time still covered by the manufacturers' warranties, so their mileage was relatively low.

Fig. 5. Thermograph of a drive belt transmission in thresher harvesters Claas Lexion 760

4. SUMMARY

On the basis of the thermo-visual measurements taken, it is possible to draw conclusions on their usability in the diagnostics of grain harvester belt transmission systems. This approach is quite promising, as shown with the example of the transmission system in the John Deere 1450 harvester. The local temperature build-up, as shown on the thermographs (Figs. 4a-b), appearing in the bearing node areas of the pulleys, was a result of their poor technical condition, which was confirmed with a recommendation for their replacement given by an authorized John Deere servicer.

The results of the study provide some grounds for a positive assessment of the method adopted. The authors obtained sufficient premises for continuation of the experimental research, aimed at further development of a data basis for heat loads affecting the components of belt transmission systems, as well as determining what conditions for cooperation, as described with the temperature distribution and its absolute values, should be taken into account when deciding whether to start maintenance/servicing in the grain harvester operation process. In this respect, cooperation with the machine manufacturer's service teams, in order to refer our test results to diagnostic information gathered in the course of routine or emergency service actions, is necessary. The final effect of such cooperation could be preparation of a measurement-based map of the belt transmission system components, with the identification of the temperature probing points. This requires correlation between the bearing node working temperatures and their actual technical condition, in order to identify the border temperature value that necessitates their repair.

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