Diagnostics of the Thermal Condition of the Cable Gear Used in the Drive of a Wood Chipper

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Abstract. Early detection of the causes of malfunction of toothed gears, cable gears, and various types of drives enables the prevention of breakdowns and related downtime. The work concerns the possibility of using terminography in order to assess the thermal state of the V-belt of the tension transmission used in the drive of a wood chipper. This device is exposed to dynamic loads and one of the main elements transmitting the drive is a cable gear with a V-belt. The paper presents the use of thermography to evaluate the operation of a cable gear with a heat-welded V-belt. As a diagnostic characteristic, the dependence of temperature changes of the belt and pulleys on the variable load of the chipper over time was adopted. The variable load on the device results from the feeding time of the branches and their cross-section. The aim of the work was to investigate the influence of variable transmission load on the durability and life of the V-belt. It has been found that for the cable transmission it is desirable to ensure that the temperature of the belt around the circumference is similar and changes little.

1. Introduction
The use of V-belts in cable transmissions dates back to the beginning of the 20th century, however, in the last dozen or so years, the intensive development of industry contributed to the improvement of the existing, developed forms of geometric drive and transport belts. The cause of improper operation of the traction gears may be mistakes resulting from incorrect selection of geometrical features of the gear, errors occurring during the manufacture of wheels, incorrect assembly of the gear [1-3], incorrect geometry of details during spinning [4-6], premature destruction of parts [7-8], change in temperature of the gear [9-10] the last feature may cause the belt to elongate too quickly and, consequently, destroy it. The V-belts used in cable gears are most often made of composite materials with a composition based on plastics [11-14]. So far, the production of tension belts has traditionally used steel or polyamide cords constituting the load-bearing layer, rubber or caoutchouc to make the flexible layer, and a fabric-rubber composite for the protective layer. Due to their mechanical properties, V-belts are used in transport systems where other strings do not meet the functional requirements [15-17]. Examples of such applications are conveyors transporting products at high speeds, exposed to significant abrasive wear, in difficult environmental conditions [18, 19]. Thermography is used to diagnose kinematic nodes in rotary mowers [20] or to analyze the stability of the process of extrusion of microporous polyvinyl chloride (PVC). In the literature, you can find many examples of the evaluation of belt transmissions with flat, wedge and toothed belts where thermal imaging cameras were used [21-25]. The principle of operation of such solutions is based on the indirect measurement of the temperature of the analyzed object, while the emission power generated by the object is directly assessed [26-31]. The emission of the object is converted, using the system's detection system, into an electrical impulse which is a means of informing about the thermal state of the object. The thermograph makes it possi-
able to determine the temperature, while the thermometric characteristics are placed on the computer disk which enables the visualization of the thermograph by the camera.

During the temperature from the application of thermovision values, errors (error of the emissivity test of the object, error related to the error test) and calibration, errors related to the measurement test. The principle of carrying out thermal imaging measurements is described in [9].

The objective of the study was to assess the thermal condition of the cable gear used in the drive of a wood chipper. The knowledge of the temperature changes of V-belts is important when selecting both the type of belt and possible applications. The test results can be used in the process of selecting belts used in heavily loaded transmissions as well as for people involved in work safety in enterprises using machines and devices with cable transmissions.

2. Research methodology
2.1. Subject of research
A belt drive of a wood chipper [32-34] with two A 1500 V-belts operating in parallel and a cross-section of 13x8 was selected for the study. Due to the color and lack of gloss (the wheels were covered with rust coating), it was not necessary to paint them. The experiments used a thermal imaging camera called Termovision FLIR T620, which has a spatial resolution of 0.62 mrad, the accuracy of measurements for this camera is ± 2 °C or ± 2% of the measured value.

2.2. Test stand and the course of examinations of the thermal state of the gear
The tests of the cable gear driving the wood chipper were carried out in December at an ambient temperature of -2°C. The driving wheel was mounted on the motor shaft, and the driven wheel was the shaft drive on which the chipper knives were mounted. The gear worked as a reducer, the ratio was 1: 5. The gear load was applied by periodically feeding the branches to the chipper. The course of the research was as follows: after starting the station and idling for 5 minutes, the branches were supplied to the chipper. In the first stage, this work was performed by one operator. After filling the container, there was a short break for its replacement and then the material was supplied to the device by two operators. Due to the fact that the cross-section of the branches was different, it generated a variable load on the transmission. When branches with a diameter of more than 70 mm were given, the drive sometimes stopped and the temperature rose sharply. The following distances of the branches from the chipper were assumed (3, 9, 15 meters) [35]. The test stand for the assessment of the impact of load on the temperature of V-belts is shown in Figure 1.

![Figure 1. Test stand to assess the impact of load on the temperature of V-belts.](image-url)

3. Research Results
The result of the performed experimental tests are information on the values of the current temperature of the belts recorded on thermal images (thermograms) and their distribution illustrated on the profilograms. To facilitate the assessment, the red color is assigned to the active cable, while the green color is the passive cable. In order to carry out thermal analysis, a specialized computer program ThermaCAM Reporter 2000 Professional was used. Profile lines of the active and passive tendon were assessed (Fig. 2).
Figure 2. The designation adopted in the temperature measurement procedure of the tension gear belts with a V-belt.

The instantaneous temperature values during the gearbox operation without load are shown in Figure 3a, while the temperature distribution for these operating conditions is shown in Figure 3b. During this time, the camera recorded the absolute temperature difference as a value of 0 °C between the temperature in the active (upper) cable and the temperature in the passive (lower) cable. The analysis of Figures 3a and 3b shows that the temperature difference of $\Delta T = 0.0$ degrees indicates the correct operation of the measuring apparatus.

Figure 3. Temperature distribution along the lines li01 and li02 recorded with the transmission stationary, red - active cable, green - passive cable.

Figure 4 shows the temperature change on the tendon surface after 1.32 minutes, when the weight of the chips was 33 kg. The branches were fed to the device by one operator. The distance of the branches from the shredder was 3 meters. An increase in the mean temperature was observed in the active cable (38.8 °C) in the relaxation phase and in the inactive cable (33.7 °C) in the dropping phase from the driving wheel. The recorded temperature change of the belt was caused, on the one hand, by its significant stretching when starting cooperation with the driving pulley, and on the other hand, by its compression before leaving the cooperation (Fig. 4a).

Figure 4. Temperature distribution along the lines li01 and li02 recorded after 1.32 minutes from the commencement of comminution, (one operator, distance between the branch and the chipper 3 meters) red - active cable, green - passive cable.
In subsequent experiments, Figure 5 shows the temperature distribution on the V-belt and the profilograms recorded during the work of two operators. The temperature was recorded after 15 minutes when the weight of the wood chips obtained was 208 kg. In this test, a significant increase in the average temperature was recorded both in the active cable (approx. 73.3 °C) and the passive one (64.75 °C), the difference in temperature was $\Delta T = 8.55$ degrees C. The ambient temperature was then 0 °C.

The next experiments were carried out 26 minutes after the commencement of grinding, then a total of 402 kg of wood chips was obtained, the results are included in the drawing 6. The analysis of the obtained belt temperature distributions and the performed profilograms indicate a gradual reduction and equilibrium of the temperature in the active (approx. 37.9 °C) and passive (34.7 °C) cable was observed. There were vibrations in the active band which additionally lowered the temperature of the belts.

In turn, Figure 7 shows the change in belt temperature and recorded profilograms recorded during the second stage of the tests at a distance of 9 metres, but branches with a diameter of about 100 mm were given. After producing the first 30 kg of chips, a very rapid increase in the average temperature was observed in the active cable (75.9 ° C) during entering and in the passive cable (67.6 ° C) when leaving the driving wheel. Then, with the adopted rules for conducting the experiment, an increase in the temperature difference between its values in the active and passive cables was observed, equal of $\Delta T = 8.3$ °C. Such a high temperature of the belts was caused by the operation of the device during very unfavorable working conditions.
After 26 minutes, further experiments were carried out using thermal imaging technology. After this time, 189.5 kg of wood chips were produced. The recorded values of instantaneous temperatures and their distribution on the circumference of the belt are included in Figures 8a-b. It was observed that the difference between the temperature in the active (77.6 °C) and passive (70.6 °C) tendons, equal to \( \Delta T = 7 \, ^\circ \text{C} \). It can be concluded that there is a direct correlation between the temperature of the wheels and the temperature of the V-belt.
In the figure (Fig. 9a) please see the terminogram made on the playback side 42 min. You can then turn on the stabilization of temperature changes. The temperature of the tendon joining the active pulley (82.5 °C), while the temperature of the passive cable fluctuated around the value (76.1 °C). At that time, the temperature difference in the tendons between the active (82.5 °C) and passive tendons was (approx. 6.4 °C). In (Fig. 9b) there are profilograms describing this condition of the transmission, the stabilization of temperature distribution is visible.

The thermographic image (Fig. 10a) observed during the experiment at a distance of 15 meters, branch diameter approx. 100 mm, is very interesting due to the analyzed aspects of the operation, as well as for engineering practice. The temperature distribution at several belt measurement points was measured and the temperature of the passive cable was found to be lower than that of the active cable. Between the temperature of the active (71.25 °C) and passive (63.8 °C) cables, the difference was $\Delta T = 7.45$ °C (Fig. 10). Such a behavior of the transmission under the export conditions tested is caused by cooling down due to transverse vibrations of the belt.

![Figure 10](image)

**Figure 10.** Temperature distribution along the lines li01 and li02 recorded 3.35 minutes after the commencement of comminution, (one operator, the distance of the branch from the chipper 15 metres) red - active cable, green - passive cable.

Figure 11 shows changes in V-belt temperature and profilograms recorded during the third stage of the tests after 24 minutes at a distance of 15 meters, branches with a diameter of about 100 mm were fed. After the first 30 kg of chips were produced, a very rapid increase in the average temperature was observed in the active cable (78.08 °C) in the entry phase and in the passive section of the belt (72.15 °C) during its exit from the driving pulley.

![Figure 11](image)

**Figure 11.** Temperature distribution along the lines li01 and li02 registered, registered 24 minutes from the commencement of comminution (two operators, the distance from the branch to the chipper 15 metres), red - active cable, green - passive cable.
In the tested case, under the given conditions of the experiment, an increase in the temperature difference between the temperature values in the active and passive cable was observed, corresponding to the value of \( \Delta T = 5.93^\circ C \). Such a high temperature of the belts was caused by the operation of the device during very unfavorable working conditions.

Figure 12 shows the temperature distribution of the belt and the profilograms recorded during the third stage of the tests, after 48 minutes at a distance of 15 meters, the branches with a diameter of about 100 mm were fed. After producing 261 kg of chips, a very rapid increase in the mean temperature was observed in the active cable (75.945 \( ^\circ C \)) in the relaxation phase and in the passive cable (62.5 \( ^\circ C \)) in the drop-off phase from the driving wheel. In the tested case, under the given conditions of the experiment, an increase in the temperature difference between the temperature values in the active and passive passive was observed, corresponding to the value of \( \Delta T = 12.95^\circ C \). Such a high temperature of the belts was caused by the operation of the device during very unfavorable working conditions.

The last thermogram was recorded after the belt was broken. It took place immediately after recording the thermogram presented in Figure 13. It was caused by a very fast increase in belt temperature caused by blockage of the shredder.

Figure 14 shows the relation of belt temperature change to capacity for a branch distance of 3 m from the chipper.
Conclusions
The paper presents the results of thermal imaging tests of a tension transmission with a V-belt used to drive a wood chipper. The correctness of gear operation was assessed on the basis of temperature changes on the belt surface. According to the authors, there is a relationship between the characteristics of the friction process, transmitted power, efficiency, load and material properties of the V-belt, etc. Summarizing the observation results, it should be stated that the thermal imaging camera is an appropriate tool to assess the warm state of the V-belt transmission used in wood chippers. Based on the tests, it can be concluded that: for a distance of 3 meters from the shredder, at the initial stage and in the final operation of the machine, a stabilized temperature was recorded in the active cable of approx. 38 °C and the passive of 34 °C. A large increase in temperature was noted when working with two operators, then the temperature in the active cable was about 73 °C and the passive cable temperature was 65 °C. This was due to the high load on the transmission and its continuous operation without idling. For a distance of 9 meters from the shredder, a similar temperature of about 80 °C was recorded in the active cable, and in the passive of 74 °C in the entire time interval. The reason for maintaining such a high temperature was the large cross-section of branches of approx. 100 mm (constituting the limit load of the machine).

For a distance of 15 meters from the shredder, a gradual increase in temperature in the active cable was recorded. Despite the greater distance from the machine, the temperature rises dangerously, approaching the limit values given in the catalogues of belt manufacturers. It is essential to choose a belt for such difficult working conditions. Figure 13 shows the final stage of the operation of the gear subjected to a very high load. This caused the temperature of the belt to rise to about 160 °C and consequently its breaking. High temperatures may cause the belts to merge or break [36, 37].

On the basis of the conducted tests and analyzes, it can be stated that in order to ensure failure-free operation of the wood chipper, one should strive to unify the temperature in the entire V-belt. The conducted experimental studies to assess the thermal condition of mechanical devices confirmed the usefulness of thermography in the diagnosis of the technical condition of cable gears with a classic V-belt, and the obtained results will certainly be useful for the designers using gears [38-40] and the people dealing with maintenance in enterprises.

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