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Usage of IR thermography in researching of uneven strand transmissions with cogbelts

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Abstract

Issues of thermal phenomena occurring during acting of uneven strand transmissions with cogbelt there are presented in the paper. Researches were carried out with the use of IR thermographic camera ThermaCAM 2000. Example thermograms made during the work of uneven transmission for different rotational speeds and for changeable load conditions there are presented in the elaboration. Elaborated research methodology should take into account non-standard process of belt and noncircular pulleys coupling. Research results will be used for analysis of functioning, manufacturing accuracy of particular elements and uneven transmission assembly correctness.

Keywords: noncircular pulleys, IR thermography measurements, manufacturing accuracy.

Zastosowanie termografii w badaniach nierównobieżnych przekładni cięgnowych z pasem zębatym

Streszczenie

W artykule przedstawiono problematykę badań zjawisk cieplnych występujących w czasie pracy nierównobieżnych przekładni cięgnowych z pasem zębatym. Charakterystyczną cechą tych przekładni jest możliwość uzyskania okresowo zmiennych cech kinematycznych takich jak prędkość, i przełożenie dzięki zastosowaniu w klasycznej przekładni cięgnowej z pasem zębatym kół o nieokrągłej obwiedni. Badania przeprowadzono z zastosowaniem kamery termograficznej ThermaCAM 2000. Scharakteryzowano proces pomiaru i aparaturę badawczą zastosowaną w procesie rejestracji emisyjności efektywnej farb stosowanych do pokrycia kół nieokrągłych. Zilustrowano badania eksperymentalne dotyczące wyznaczania współczynnika emisyjności w zależności od rodzaju zastosowanej farby. W pracy zawarto ilustrację przykładowych termogramów wykonanych podczas pracy przekładni nierównonieżnej dla różnych prędkości obrotu oraz zmiennych warunków obciążenia. Opracowana metodyka badań powinna uwzględnić niestandardowy proces sprzężenia pasa i nieokrągłych kół pasowych. Wyniki badań zostaną wykorzystane do analizy funkcjonowania, dokładności wykonania poszczególnych elementów oraz poprawności montażu przekładni nierównobieżnych.

Słowa kluczowe: pasowe koła nieokrągłe, pomiary termograficzne, dokładność wykonania.

1. Introduction

A great competition between dynamically developing types of strand transmissions with: chain, vee-belt, complex belt, cogbelt inspires designers and manufactures to increase their functional and practical characteristics. One of numerous methods of manufactured cogbelts quality increase is accommodation their production to new evaluation criteria of structural materials of which belts are manufactured.

It concerns mainly transmission of higher power and reliability increase. It consists in complex recognition of mechanical and rheological characteristics of used belts in the range of their strength and rheological features and in elaboration of new designing trends for belts of classical materials. New design development trends of strains base on physical phenomena better recognition during shape-frictional coupling, and these trends lead to:
- improving of their geometrical features,
- elaborating of the new methods and techniques for determining of stress and strain state,
- improving of former materials features e.g. directional anisotropy, implementing of material structure orientation and mechanical stabilization and material memory use,
- elaboration of new manufacturing techniques for elastomer and polyamide materials.

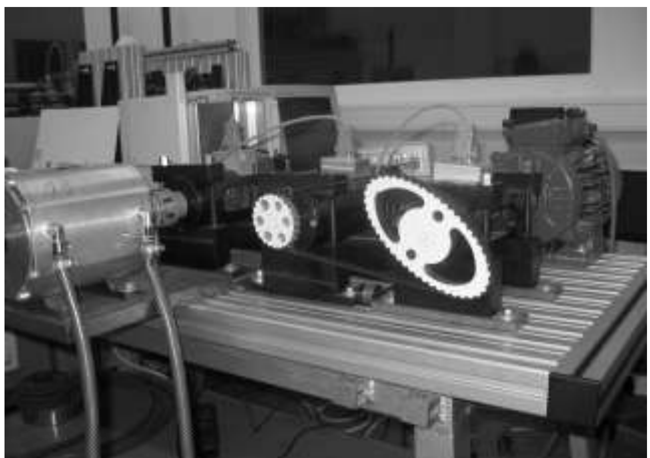

Fig. 1. Two pulleys uneven strand transmission with cogbelt
Rys. 1. Dwukołowa nierównobieżna przekładnia cięgnowa z pasem zębatym

Another direction of strand transmission expansion is creating gears which were formed of new machine's connection classical elements. Example of such new designs is uneven strand transmission [1], [2], [3]. Demanded degree of unevenness is obtained by the use of belt transmission, wheels of which rim perimeter has the oval, ellipse shape, noncircular discs (Fig. 1). The use of chain strains in such transmissions is well known.

Whereas the problem of cogbelt use in these transmissions is not recognized till now. Correctness of noncircular pulleys toothing designing have to be verified both by carrying of analysis with simulation method and on physical models. It will enable the correctness verification of shape-friction coupling between gear wheel and synchronous cogbelt [4]. Very important utilitarian and cognitive meaning has carrying out of full and complete describing and interpretation of processes and phenomena happening in the moment of mating of cogbelt with toothed pulley with noncircular rim envelope.

2. Research issues characteristic

Process and phenomena happening during mating of cogbelt with noncircular toothed pulleys were presented in the book [1]. In transmission with noncircular wheels the shape-friction coupling process is characterized with significant differences resulting from different geometrical features of wheels (elliptical, oval) and different kinematical features. Basic problem which occurs in coupling characteristic of such transmission is necessity of designing of indicating dial on noncircular pulley. It generates the necessity of toothed pulley „constant" pitch matching to instantaneous toothing conditions of the transmission. Problem of cogbelt pitch variability have to be taken into consideration during designing of noncircular wheels geometry in system CAD being the base of designing of technology and manufacturing process of the wheel. Manufacturing of such designed wheel rim is possible in machining processes e.g. profiling with end mill use, cutting with the use of numerically controlled wire erosion machines, cutting with water-laser and abradant. One of the conditions of these new transmissions propagating is reliable evaluation of their particular elements as well as the whole transmission in aspect of geometrical and kinematical accuracy, and functioning, heat and material etc. One of the conceptions is carrying out of experimental thermo-graphic research. Research results analysis should give a number information concerning the transmission heat state, correctness of used materials for operating elements, errors arisen in transmission manufacturing and assembling process.

3. Test stand and measurement methodology

For heat condition evaluation during strand uneven transmission operation there was used thermographic camera type ThermaCAM 2000 SC of company FLIR (Fig. 2). This appliance enables to carrying out measurements with thermal resolution of 0.1 ºC (in sense NETD for 30 ºC). During radiational measurements of temperature with thermographic systems there are three kinds of measurement uncertainty: uncertainty connected to the method itself, uncertainty of calibration and uncertainty caused by electronic circuit [5], [6]. In case of camera type ThermaCAM 2000 SC components of these uncertainties can generate the measurement uncertainty amounts up to ±2°C or ±2% of measuring range depending on which of these values is bigger (it refers to measurements carried out in conditions close to calibration conditions). Researches carried out with finite difference method and with the use of outer reference temperature source, enable to decrease the uncertainty of thermographic measurements, carried out in laboratory conditions, up to about 0.5°C. Toothed wheels of uneven transmission were made of metal what caused that for researches they had to be evenly coated with paints of high emissivity for tests connected to temperatures distribution (small coefficient of metals emissivity makes difficult carrying temperature measurements with radiational methods).

Emissivity is a parameter describing radiative properties of the tested object. Thermographic systems measure indirectly temperature of searched object; measuring directly the power of infrared radiation emitted by the object. Radiation emitted by tested object is converted by system's detection structure into electric signal, which is the carrier of information concerning temperature of the object.

Fig. 2. Kit for researches of heat concentration in uneven strand transmission
Rys. 2. Zestaw do badań koncentracji ciepła w nierównobieżnej przekładni cięgnowej

Temperature is calculated with the use of thermograph thermometric characteristic (calibration curves) recorded in the memory of the single-purpose computer destined among others for controlling of restoring process of temperatures fields pointed by thermograph camera. In calibration conditions the emissivity of object is precisely determined. Conditions of real measurements often are significantly different than calibration conditions. These differences cause that signal on detector exit is different than signal in calibration conditions, what increases temperature measurement uncertainty. Dominant components of uncertainty are connected to the measuring method (carried out in conditions different than calibration conditions) and uncertainty caused by measuring circuit. Each temperature measurement carried out with radiational methods is connected to the necessity of putting to the system values of parameters describing emissive features of tested object; there is needed „a priori" knowledge of this object emissivity. There can be considered three cases of emissivity influence on results of temperature radiational measuring methods referring to three different classes of IR measuring systems. There are systems operating in the whole spectrum, band systems and monochromatic systems (practically quasi-monochromatic). Thermographic devices are band systems. In accordance to typical procedures, correction of emissivity influence on measuring signal is not connected to putting into computer's system spectral emissivity characteristic, but is connected to putting one value of effective emissivity. Object effective emissivity is defined as emissivity of the grey body of the same temperature like searched object, for which signal on exit of measuring system is identical like signal of real object. In literature of this subject there is possible to meet some other ways of effective emissivity defining [7, 8]. There was shown that in case of band systems there is the best of all to use effective emissivity ε_{ef} of searched object of temperature T_{ob} understood as a weighted average of real-valued function of object spectral emissivity $\varepsilon_R(\lambda)$, object spectral luminance $L(\lambda,T_{ob})$ and spectral characteristic of camera in reference to the product of last two mentioned functions.

As the thermograph camera spectral emissivity of searched object $csk(\lambda)$ here is understood the product of function of detector's spectral relative sensitivity, optical system spectral transmissivity and spectral transmissivity of filters: $csk(\lambda) = s(\lambda)\ \tau_O(\lambda)\ \tau_F(\lambda)$. Effective emissivity of searched object is described by the following formula:

$$\varepsilon_{ef} = \frac{\int_{\lambda_1}^{\lambda_2} \varepsilon_R(\lambda) L(\lambda, T_{ob}) csk(\lambda) d\lambda}{\int_{\lambda_1}^{\lambda_2} L(\lambda, T_{ob}) csk(\lambda) d\lambda} \qquad (1)$$

So effective emissivity ε_{ef} of the particular object depends on spectral emissivity of this object, and also on individual spectral features of measuring circuit of thermograph used for searches. Measurement of effective emissivity ε_{ef} of paint, which was used for coating of transmission elements, were carried out on the measuring stand, and the main constituent of this stand was infrared radiator of flat radiation surface which was made as a tank of thermally insulated walls and flat (changeable) radiation surface made of thin copper plate (Fig. 3). This tank is connected with ultra-thermostat which is filled with water, and is equipped with pump enabling forcing of circulation through infrared radiator. Temperature control system of ultra-thermostat enables to making temperature changes in range from 30 to 90^{o}C and keeping it up on given level with accuracy +/– 0.05^{o}C. Water from ultra-thermostat flows around radiation surface of radiator and stabilizes its temperature. Value of this temperature may be measured with laboratory glass mercurial thermometer or with electronic thermometer with resistance sensor type Pt1000. Temperature may be read out with accuracy +/– 0.05^{o}C. Searched protective coats are spread on changeable plates of radiator's radiational surface.

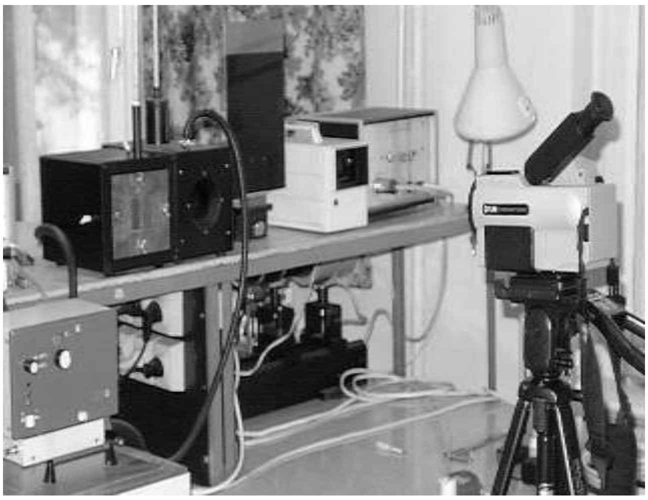

Fig. 3. View of measuring stand for measuring paint's effective emissivity
Rys. 3. Widok stanowiska pomiarowego do mierzenia emisyjności efektywnej farby

There were searched emissive features of some kinds of paints (Fig. 4). Searches showed that polyvinyl paint is characterized by advantageous emissive features. Emissivity coefficient of this paint practically does not change in temperature range from 30 to 90 ºC and its value is 0.9. There was decided that with such a paint there would be coated elements of tested transmission.

Searching stand for testing of uneven transmission was designed and manufactured in Chair of Basis of Machines Design, Poznan University of Technology. On this stand there were carried out researches concerning kinematical features and transmission dynamics of different uneven transmissions. Tests were carried out in ambient temperature equal to 21.2 ºC. The stand has modular structure. It consists of two sets of transmissions connected in series. The transmission is driven by asynchronous motor. The transmission load is given by magneto-rheological brake. Because of its design it is cooled with water stream.

The driving wheel was elliptical wheel assembled on a shaft with bearings coupled by flexible clutch to the shaft of driving motor. Figure 5 presents the thermogram recorded after the first minute since measurement starting (without transmission load). The direction of driving wheel was clockwise. Already since the first minute there can be clearly seen the temperatures difference on the driving (ellipse) wheel and on the driven wheel (noncircular) what is resulting from transmission ratio equal to 2.

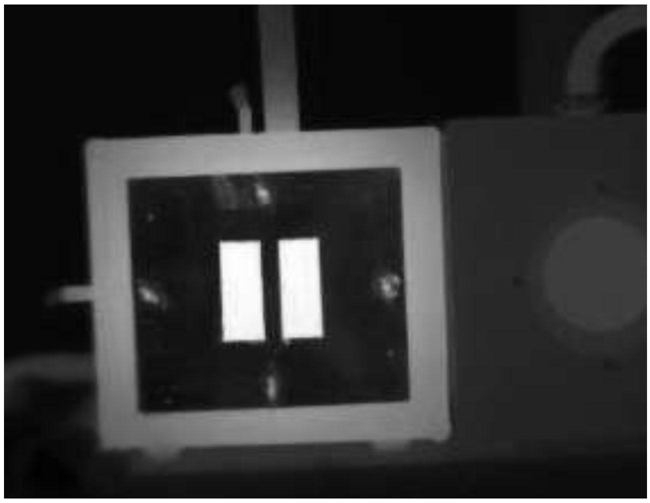

Fig. 4. Thermogram of plate covered with paint coats
Rys. 4. Termogram płytki z naniesionymi powłokami farb

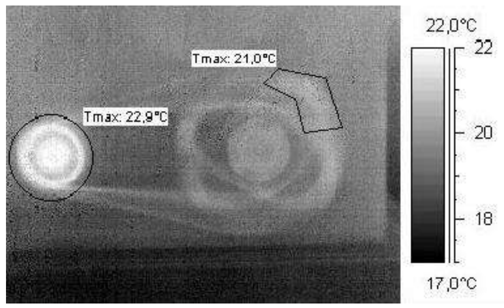

Fig. 5. Thermogram recorded after the first minute
Rys. 5. Termogram zarejestrowany po upływie pierwszej minuty

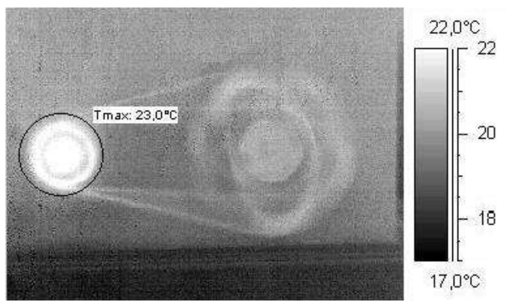

Fig. 6. Thermogram recorded after ten minutes
Rys. 6. Termogram zarejestrowany po upływie dziesięciu minut

Besides there can be noticed the increased heat concentration on the side of the belt entry into meshing with elliptical toothed wheel. After ten minutes since transmission starting (operation without load) there appears the increasing of temperature in the strand on the side of running up and phase of running down of the driving wheel (6). It is certainly caused by strand's high tension during belt's coming into meshing with driving wheel. Also there occurs the same phenomena just before belt demeshing with this wheel when the belt will be compressed. Figure 7 presents thermogram after 30 minutes since starting the first temperature record. At this moment the transmission was stopped and actual view was immediately recorded. There can be noticed the increase of temperature on the driven wheel up to 23.1ºC, and on the driving wheel up to 22.5ºC and in the belt up to 21.3ºC. There occurred high heat considerable concentration on sides of running up and down of the strand.

Next stage of searches is testing of transmission with load. For this purpose there was used magneto-rheological brake controlled with voltage of typical controller. In Figure 8 there is presented thermogram recorded for the speed of driving shaft equal to 500 rpm and for load of 5 Nm. Work with load forced a steady increment of temperature in all considered transmission's elements. This is a feature which has got an advantageous influence on coupling process which can be found in this transmission. There are clearly shown differences in heat concentration in the driving part of strand (upper one) and in the driven part, down one.

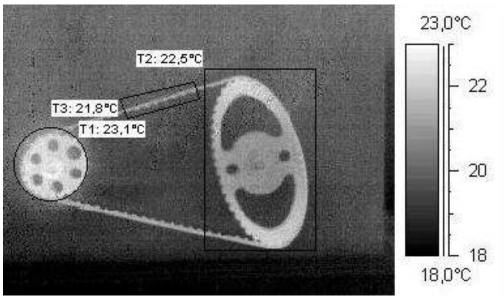

Fig. 7. Thermogram recorder after thirty minutes
Rys. 7. Termogram zarejestrowany po upływie trzydziestu minut

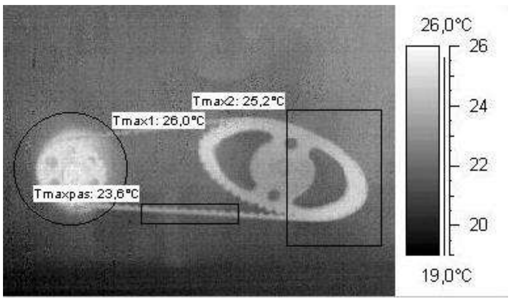

Fig. 8. Thermogram recorded for speed 500 rpm and load 5 Nm
Rys. 8. Termogram zarejestrowany przy 500 obr/min obciążeniu 5 Nm

Last presented thermogram (Fig.9) was recorded after stabilizing of rotational speed of shaft on level of 600 rpm for given load equal to 10 Nm. Recorded temperature differences of both wheels are close to each other (0.5 ℃), what has certainly advantageous influence on coupling process and life time of transmission.

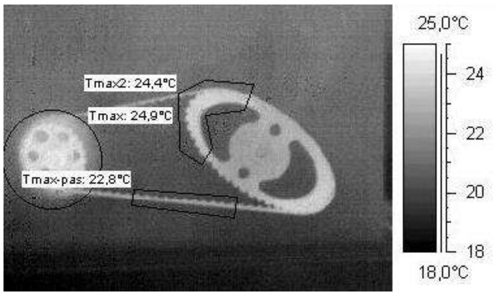

Fig. 9. Thermogram recorded for speed 600 rpm and load 10 Nm
Rys. 9. Termogram zarejestrowany przy 600 obr/min i obciążeniu 10 Nm

4. Summary

The trial of IR thermography use for correctness analysis of designed geometrical, material and kinematical features of uneven transmission with cogbelt there is presented in the paper. Carried out research has shown IR thermography use purposefulness for heat conditions testing of transmission operating in different loading conditions. Recorded results of measurements serves for full knowledge about shape-frictional coupling phenomena occurring in strand uneven transmission with cogbelt.

5. Literatura

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Artykuł recenzowany