THERMOGRAPHIC CAMERA USE IN BRAKE ORIENTED FRICTION MATERIALS TESTS

UŻYCIE KAMERY TERMOWIZYJNEJ W BADANIACH HAMULCOWYCH MATERIAŁÓW CIERNYCH

Zbigniew Skorupka

Instytut Lotnictwa

e-mail: zbigniew.skorupka@ilot.edu.pl

Abstract: Friction brake temperature due to its influence on brakes' operation is subject to many test and studies. Measurements methods of this important brake parameter are being continuously developed. In order to withstand difficulty in temperature evaluation in full brake system as well as in isolated friction pair is use of contactless measurement methods. Currently, the most widespread contactless testing method of the thermal effects is to measure infrared emission by pyrometers or thermographic (infrared) cameras. Thermal imaging method wasn't used so far during aviation brake materials usefulness evaluation and certification testing performed in Instytut Lotnictwa Landing Gear Laboratory. In this paper, author described performed friction materials tests which were recorded with thermal imaging camera as well as evaluated usefulness of the method by comparing its accuracy to thermocouple measurement.

Keywords: friction pair, temperature measurement, themographic camera, brake

Streszczenie: Temperatura w hamulcach ciernych, z powodu wpływu na działanie hamulców, jest przedmiotem wieloletnich badań i analiz. Metody pomiaru tego istotnego parametru pracy hamulca parametru podlegają ciągłemu rozwojowi. Jednym ze sposobów na poszerzenie możliwości pomiarowych w badaniach hamulców ciernych jak i wyizolowanych próbek materiałów ciernych jest zastosowanie metod bezstykowych. Na chwile obecną najbardziej rozpowszechniona metodą bezstykowych badań zjawisk termicznych jest pomiar emisji podczerwonej poprzez pirometry lub kamery termowizyjne. W badaniach materiałów ciernych wykonywanych w Laboratorium Podwozi Lotniczych Instytutu Lotnictwa na potrzeby oceny przydatności i certyfikacji lotniczej, metoda termowizyjna nie była dotychczas stosowana. W przedstawianej pracy autor opisał możliwości wykorzystania kamery termowizyjnej do rejestracji badań materiałów ciernych. W ramach wykonanych prac ocenił dokładność metody przez porównanie wyników z niej uzyskanych z wynikami rejestracji termoparowych.

Słowa kluczowe: para cierna, pomiar temperatury, kamera termowizyjna, hamulec

1. Introduction

Temperature measurement in friction brakes is one of the main topics in mechanical research for decades [2]. It is due to temperature itself that influences brake performance in critical way. In most of the cases higher temperature lowers the coefficient of friction up to the point where braking is no longer possible. Because of the security reasons braking must be guaranteed in every case it is required.

Biggest problem in temperature measurement in brakes is inaccessibility of zone where the most of heat is generated. Friction brake design is also unfriendly in terms of research due to rotating parts. Rotational movement of brake rotors makes virtually impossible of direct temperature evaluation by currently most common and reliable method such as thermocouples. Nowadays thermocouples are recognized as the best way to obtain accurate temperature readings but its usage is limited to areas where no moving (especially rotating) parts are. In brake both model (as in friction pair/material tests) and full scale, area of interest lies not only in stator but also in rotor of the brake and in friction surface area. In order to measure temperature there (rotor or/and friction surface area) it is needed another, contactless method. The best option is to use thermographic (infrared) camera that is a powerful measuring device due to its capabilities. Of course it is not a perfect solution, it is rather completion to widely used.

2. Thermographic Camera

Thermographic camera (infrared camera, thermal imaging camera) is a device that measures infrared radiation of object surface. Amount of emitted radiation is depends of actual body temperature. Intensity of radiation depends of objects' material and is called emissivity. Emissivities for broad range of materials are known and easy to find in engineering sources. It is necessary to remember that metallic materials (in opposition to most of non metallic ones) change its emissivity due to surface state or treatment.

Emissivity as material constant is defined as body's ability to emission of radiation energy. Emissivity can fluctuate from 0 up to 100%, depending on material type, colour and its surface state. For example "body perfectly black" is ideal source of radiation and its emissivity is equal to 1.0 (100%), unlike mirror with emissivity as low as 0.1 (10%)

Most of the materials change its emissivity according to temperature change what result in simultaneous change in amount of radiation and its value. Such behaviour can and results in decrease of temperature measurement accuracy. Because of this, thermographic measurements are best in order to evaluate temperature changes (in order to draw proper characteristics) in time or to evaluate one temperature value (or very narrow range of it) in case of stable emissivity. There is a possibility of

taking into the account changeable emissivity, but only for well-known objects where emissivity was evaluated earlier for as many temperature points as possible. In measurement point of view, proper emissivity adjustment is important due to fact that if its value were too high temperature readings would be too low and otherwise. Shiny and well reflective materials are also subject to wrong readings because of its low emissivity what are comparable to reflections in view of measuring system. It is crucial not to let any of reflections, shines or flashes to be able to obstruct optical field of camera.

Sample average emissivity values of several materials are shown in table 1.

Tab. 1 Sample average emissivity values of several materials

Material	Surface Treatment	Average Emissivity
Aluminium	Not Oxidized	0,02-0,1
	Polished	0,02-0,1
	Rough	0,1-0,3
	Oxidized	0,2-0,4
Steel	Polished	0,1
	No Rust	0,1-0,8
	Raw	0,4-0,6
	Cold Rolled	0,7-0,9
Cast Iron	Coated	0,7-0,9
	Not Oxidized	0,05-0,2
	Rusty	0,5-0,7
	Oxidized	0,5-0,9
Asbestos	Forged, Rough	0,9
	-	0,95
Carbon	Not Oxidized	0,8-0,9
	Graphite	0,7-0,8
Water	-	0,93

Every thermographic device has two main components (except main wave detector) that determine its measurement capabilities, namely optics and spectral filter. Optics or optical system is defining optical range of camera, its zooming capabilities, and amount of light, which is transferred to the detector and view area to be covered during measurement. Spectral filter is a device used to filter and to allow only selected wavelengths, important for temperature evaluation, to pass to the wave detector. Typical waveband is between 1 μ m and 20 μ m.

Wave detector and its control system is used to converting infrared signal to electrical impulses which are later directed to acquisition system usually external computer with proper analysis/recoding software.

Main advantage of thermographic camera is ability to record image of studied object. Cameras record temperature of every separate pixel of wave detector within measurement range (number of separate points/pixels is defined by detector resolution). Such capability results in possibility of very flexible temperature evaluation (ex. in areas, single points, colour visualization of temperatures, evaluating maximal, minimal and/or average temperature).

In recent years thermographic cameras become more popular due to new EU regulations according energy classes of the buildings and are widely used in order to find spots of heat outflow in inner spaces or on facades. Another advantage of thermographic camera use is possibility of record and visualise thermal phenomena not to be seen by naked eye due to their aspects or due to possible danger to observer.

In described research author used FLIR SC645 camera (25 fps), FLIR ResearchIR software for data recording and MS Excel for analytical analysis and graph drawing.

Tab. 2 Selected technical data of FLIR SC645 camera [4]

No	Name	Value/Description
1	Temperature measurement range	-20° do +150°C 0° do +650°C
2	Spectral range	7,5 to 13 µm
3	Accuracy	±2°C or ±2% indication
4	Thermal Sensitivity	<0,05°C w +30°C/50mK
5	Detector Resolution	17 µm
6	Resolution/ Detector Type	640x480 pixel Focal Plane Array (FPA), non cooled
7	Response Time	8 ms, typical
8	Optics	Focal point 24,5 mm, F=1,0, min. sharpening 0,4 m
9	Field of View	25°x18,8°
10	Optical Transmission Correction	Automatic
11	Manual Emissivity Correction	0,01 to 1,0 (program)
12	Measurement Correction	Global (program)
13	Data Interface	USB, LAN 1Gbit

3. Measurements

All tests were carried out using IL-68 (figure 1) test stand. IL-68 is the inertial type test stand designed for friction pair materials testing mainly for brake use. The specificity of the IL-68 tests lies in fact that one tests is equal to one full braking from initial velocity $V_{\max}$ up to full stop ($V_{\text{end}}=0$). During typical tests [1] there are made 5 to 8 bed-ins for proper geometry cohesion of friction pair in contact zone (for maximal use of friction area). Next, 10 qualification test are carried out in order to evaluate various properties of braking process such as friction coefficient, wear, temperature or braking time in designated conditions.

Fig. 1 IL-68 test stand side view.

Tab. 3 Selected technical parameters of IL-68 test stand

No	Name	Value/Description
1	Shaft Maximal Rotational Speed	9000 rpm (150 rps)
2	Maximal Torque	0,154 ÷ 1,54 kgm ² (0,098 kgm ² step)
3	Maximal Clamping Force	5,88 kN

Test object in model tests is a set of samples (sectors) made out of real friction pair materials (figure 2).

IL-68 test stand allows to measure and to acquire number of test parameters such as braking torque, braking force, braking time, and rotation speed of samples. These parameters are used not only for measurement purposes but also as internal control signals for IL-68 test stand.

*Fig. 2 Example of model friction pair used in IL-68 tests
(right friction material samples, left cast iron countersample).*

Temperature measurement in this case is made by external systems and is configured accordingly to actual needs. All of measurements are acquired to PC computer for further analysis.

As it was said earlier, temperature is measured via external system. In tests that were basis for this article, temperature was measured by three methods: thermocouple, pyrometer and thermographic camera. Two first methods won't be described in this article (only one thermocouple measurement as reference will be mentioned).

Thermographic camera was used to record area of tests in order to measure both temperatures of friction pair and temperature of friction contact. As reference for temperature accuracy one thermocouple was used. Thermocouple in this case was measuring temperature of one of the friction sample outer surface (non rotating one). Camera position during tests is shown in the figure 3.

During tests there was measured and recorded number of parameters need for braking process evaluation [3]. In this article only temperature measurement will be presented. As it was written above thermographic camera allows to record temperatures in whole area covered by its optical system. During tests four temperature ranges were monitored: average temperature of friction area, temperatures of selected points on both test samples (friction pair) near contact area and temperature in the same point where surface thermocouple was mounted. There were made several tests but due to their similarity only one graph will be shown.

*Fig. 3. Thermographic camera position during tests
(there can be seen reference thermocouple in the back of the photo).*

As it can be seen there are some similarities between thermographic camera recording and thermocouple one. General behaviour of temperature curves (Thermocouple and Tcamera sample) is the similar but values are different. It is seen especially on part of the graph after 10 s timestamp. In the first 6 seconds of measurement there is seen faster temperature growth in camera recording than on thermocouple one. These phenomena can be explained mostly by affect of different measurement methods used in both devices. Thermographic camera relies on emissivity, which as it was described earlier in the text can change during the process. Thermocouple has no such issue but, due to its measurement inertia is less sensitive to fast temperature changes and (because of used signal conditioner) has its own signal filtration which smoothens obtained characteristic. Concluding it is better to use thermography as source of knowledge on temperature changes during the process and thermocouple as source of reliable temperature values. Thermographic camera on the other hand can be used to measure temperatures where no thermocouple can be mounted i.e. on moving or rotating parts.

As it can be seen in the figure 4 (“Tcamera countersample” curve), such measurement is possible and is quite simple to perform.

Fig. 4 Sample graph showing thermographic camera recorded temperature and one recorded via thermocouple.

Also measurement of the temperature change in friction contact area of brake is possible only by the camera (thermocouple will be destroyed during measurement). According to the literature and these measurements thermographic camera is best used to evaluate changes in temperatures in time not to exact measurement of temperature itself.

Another interesting fact about made measurements is thermographic camera susceptibility to external vibrations.

It can be seen on the graphs as changes of the temperatures, but these changes are not seen for thermocouple measurement due to its direct coupling with sample surface (thermocouple vibrates with the sample). Using proper filtering can reduce recording of the mechanical vibrations phenomena, but this will result in further decline in temperature measurement accuracy.

Thermographic camera also allows image recording what results in possibility of visualisation of temperature flow in observed object or allow recording many phenomena that cannot be seen by naked eye. One of such phenomena is release of hot particles from friction pair contact area. Due to its size and short cooling time, it is not possible to see it in most of the cases. Thermographic camera use allows doing that. Sample images where hot particles can be seen are shown below.

Fig. 5 Hot particles leaving friction contact during IL-68 test (sample frames from thermographic camera recording).

4. Conclusions

Thermographic camera is a very valuable tool for temperature measurement in friction materials tests. Versatility of the device allows performing data acquisition in number of measurement points simultaneously. It can be used as visualisation tool in order to see temperature flow in the friction pair as well as it allows recording and later analysing not seen by naked eye phenomena.

It is necessary to remember that thermographic cameras are rather measurement systems to record and/or view temperature changes not certain values. As for valid and accurate temperature value measurement it is still better to use thermocouple measurement.

It is noticeable that camera based measurement is somehow susceptible to mechanical vibrations of the test object (camera itself is not vibrating with the object in the same time). This behaviour can be deceptive in data analysis, but proper filtering can resolve it, unfortunately it will reflect on measurement accuracy.

In tests performed by author thermographic camera was invaluable aid in order to evaluate phenomenon involving particle emission from friction contact area. Using

infrared imaging it was possible to see emission in the first place, but also it helped to determine intensity of the phenomenon.

Also camera as measurement device can be used to determine temperatures in areas where contact methods fail especially in friction contact area and on rotating objects (such as rotating countersample on the IL-68 test stand).

It is necessary to remember that thermographic camera measurements can be done only on the outer surface of the tested object.

Concluding, it is reasonable to say that thermographic camera should be used during friction materials tests and is valuable even aid during standardised test.

5. References

- [1] Skorupka Z., Grygorcewicz P., Badania laboratoryjne hamulców ciernych w laboratorium badań podwozi lotniczych. Technika Transportu Szynowego, 2013.
- [2] Ścieszka S., Hamulce Cierne. Gliwice-Radom, 1998.
- [3] Raport, Wielopunktowe badanie temperatury modelowej pary ciernej na maszynie IL-68 przy jednoczesnym użyciu technik stykowych i bezstykowych. Instytut Lotnictwa, Warszawa 2015.
- [4] FLIR SC645 User Manual.

Zbigniew Skorupka, Finished Warsaw University of Technology, where he studied Shaping Machines Design and Control. He received his MSc in 2004. Since 2006 he has been working in the Landing Gear Department of Warsaw Institute of Aviation as a designer/researcher. His professional area is: use of smart materials in landing gear, general design and testing of landing gear, brakes and test stands.