Thermal transfer analysis of machines used for the treatment of textile materials

DOI: 10.35530/IT.075.03.202352

MARIUS DARIUS ȘUTEU
RAREȘ PANCU
TIBERIU VESSELENYI
GABRIELLA BOHM
LILIANA DOBLE

ABSTRACT – REZUMAT

Thermal transfer analysis of machines used for the treatment of textile materials

The present paper aims to introduce a comprehensive thermal analysis of the sizing-finishing machine (Squeezing Pader Machine) to identify the overheating areas to organise maintenance activities. As there is no universal application for checking the condition of a machine, specific methods must be used depending on the characteristics of the machines being monitored, as machine condition monitoring is very important in terms of productivity, economic benefits and maintenance. The thermal analysis of the equipment in this work paper, has an important role (for planning maintenance activities), because this machine ensures optimal loading with different material treatment solutions, intended for mattresses, according to customer requirements. In the present paper, the authors conducted research on the whole technological flow to plan predictive maintenance activities using online monitoring methods. The mathematical modelling of the data obtained from the thermal analysis of the engines carried out based on the polynomial regression is used to predict the evolution of the temperatures along the analysed lines outside the measurement interval for each engine analysed. In this sense, the authors propose online monitoring of the motors that have the role of stretching and transporting the material, which is not included in the real-time temperature monitoring in the machine software, as the rest of the motors are monitored. Regular monitoring of motors with the help of thermography can help identify potential problems before they become serious, allowing preventive maintenance to improve the equipment's reliability and efficiency.

Keywords: *maintenance, thermal imaging, FLIR SC 640, FLIR RESEARCH IR MAX 4.40 Software*

Analiza transferului termic al maşinilor utilizate pentru tratarea materialelor textile

Scopul lucrări este de a prezenta o analiză termică amplă la maşina de apretare-finisare HAS (Squeezing Pader Machine), pentru a identifica zonele care se încălzesc excesiv în vederea planificării activităților de întreținere. Deoarece nu există o aplicație universală pentru verificarea stării unei mașini, trebuie utilizate metode specifice în funcție de caracteristicile mașinilor monitorizate, având în vedere că monitorizarea stării mașinilor este foarte importantă în ceea ce privește productivitatea, beneficiile economice și întreținerea. Analiza termică a echipamentului din această lucrare, are un rol important (pentru planificarea activităților de întreținere), deoarece această mașină asigură o încărcare optimă cu diferite soluții de tratare a materialelor, destinate saltelelor, în funcție de cerințele clientului. În lucrarea de față, autorii au efectuat o cercetare a întregului flux tehnologic în vederea planificării activităților de mentenanță predictivă prin metode de monitorizare online. Modelarea matematică a datelor obținute în urma analizei termice a motoarelor realizate pe baza regresiei polinomiale este utilizată pentru a prezice evoluția temperaturilor de-a lungul liniilor analizate în afara intervalului de măsurare pentru fiecare motor analizat. În acest sens, autorii propun o monitorizare on-line a motoarelor, care au rolul de a întinde și transporta materialul, care nu sunt incluse în monitorizarea temperaturii în timp real în software-ul mașinii, așa cum sunt monitorizate restul motoarelor. Monitorizarea regulată a motoarelor cu ajutorul termografiei poate ajuta la identificarea potențialelor probleme înainte că acestea să devină grave, permițând întreținerea preventivă în vederea îmbunătățirii fiabilității și eficienței echipamentului.

Cuvinte-cheie: *mentenanță, imagini termice, FLIR SC 640, FLIR RESEARCH IR MAX 4.40 software*

INTRODUCTION

Research on monitoring the condition of industrial machinery is a very important area aimed at avoiding unexpected situations such as malfunctions, breakdowns, failures, shutdowns and not least economic losses [1, 2]. Infrared thermography is a non-contact condition monitoring technique that has been widely used for inspection of equipment, electrical installations, etc. A study concluded that the use of thermography for monitoring electrical motors in the textile industry can be efficient and cost-effective compared to traditional maintenance methods [3]. However, thermography has been used insufficiently for monitoring and fault diagnosis of motors used in textile equipment [4].

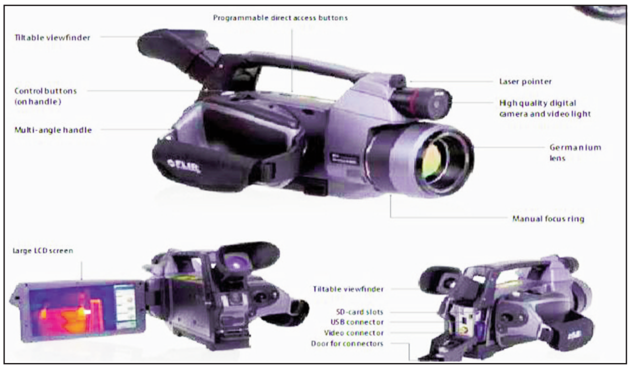


Fig. 1. FLIR SC 640 thermal imaging camera components [8]

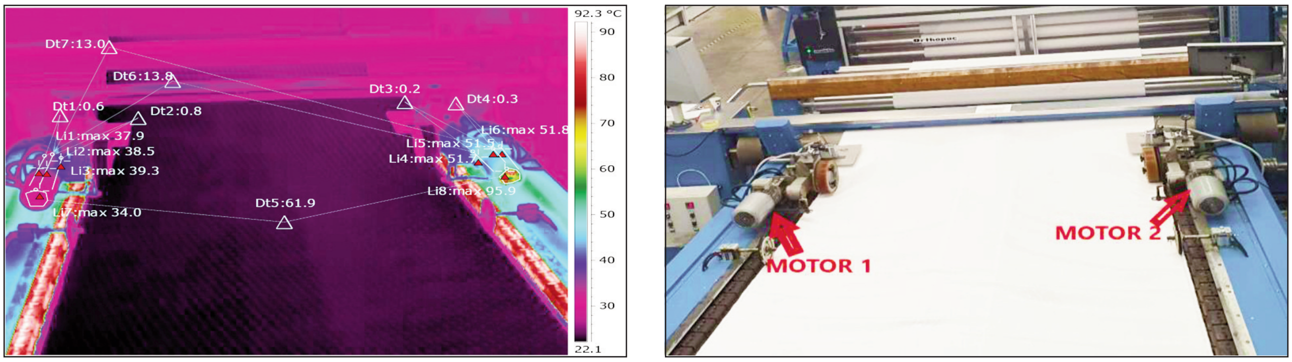
Fig. 2. Equipment for the treatment of textile materials

Regarding the scientific studies based on thermography, a series of papers has been published that analyse various important aspects regarding heat transfer; this research was conducted with the help of the infrared thermal imaging camera [5–7].

Thermography measurements were performed at the Lava Knitting in Oradea. The Flir SC 640 thermal imaging camera was used, which is a portable thermographic scanning equipment, “without cooling”, which has the strongest existing IR detector, with a resolution of 640 × 480 pixels and with a thermal sensitivity encountered so far only by cameras with cooling systems (<0.04°C) [8]. As can be seen from figure 1, the thermal imaging camera is equipped with a laser pointer, germanium lens, SD card, USB, and video connector. A great advantage of the Flir SC 640 thermal imaging camera is that it allows scanning objects remotely, with no contact, the testing being non-destructive for the objects to be measured; it ensures predictive maintenance of equipment and the detection of defects in the early stages to reduce costs. Flir Research IR max 4.40 software is used for research and development, allowing real-time analysis of the video sequence [8]. The infrared thermography examination method [9, 10] has recently entered the practice of non-destructive examinations, being a method of measuring the thermal field by recording infrared radiation and visualizing the temperature distribution on the observed surfaces [11, 12]. A condition-based maintenance approach may be used for planning the maintenance activities of textile machines with satisfactory performance [13]. Maintainability has been defined as the feature of a machine to maintain or restore its prescribed functions in the shortest possible time [14]. Therefore, maintainability depends on how failures are identified as well as on how maintenance activities are planned and carried out to prevent or eliminate the deterioration of machines [13]. Preventive and predictive maintenance are the main types of proactive maintenance strategies [15, 16] and their employment in industry has been presented in existing literature [17, 18]. The thermal analysis of the equipment in this work paper has an important role (for planning maintenance activities), of the motors (1 and 2) which have the role of setting the material on the conveyor chain to ensure optimal loading of different material treatment solutions, intended for mattresses, according to customer requirements. Regarding the various thermal analyses performed on textile materials and different equipment (e.g. sewing machines, embroidery machines) the research of this working paper is carried out on the whole technological flow (of treatment of the material intended for mattresses which has a decisive role for ensuring optimal loading with different material treatment solutions, according to customer requirements) to plan maintenance activities, although in this paper we only present a thermal analysis on the motors (simultaneous and synchronous non-functioning of the motors leads to deformation of the material on the drum and its non-conforming treatment) in the Squeezing Pader Machine.

MATERIALS AND METHODS

The state of the textile machines can be evaluated by monitoring different parameters, such as vibration and temperature [19, 20], so their maintenance can be performed a short time before the failure [21–25]. Thermographic measurements were performed on the Squeezing Pader Machine, which is a machine for treating textile materials (mattress covers), as shown in figure 2. As can be seen from figure 3 and table 1, the maximum temperature along line Li1, which is positioned on motor 1, is 37.9°C, and the minimum temperature is 31.5°C. The temperature variation along line Li1 is 6.4°C, and the emissivity is 0.80 along line Li1, positioned on motor 1. The maximum temperature along line Li2, which is positioned on motor 1, is 38.5°C, and the minimum temperature is 31.8°C. The temperature variation along the Li2 line is 6.7°C, and the emissivity is 0.80 along the Li2 line, positioned on motor 1. The maximum temperature along line Li3, which is positioned on motor 1, is 39.3°C and the minimum temperature is 30.6°C. The temperature variation along line Li3 is 8.7°C, and the emissivity is 0.80 along line Li3, positioned on motor 1. The maximum temperature along line Li7, which is positioned on motor 1, is 34.0°C, and the minimum temperature is 29.9°C. The temperature variation along the Li7 line is 4.1°C, and the emissivity is 0.80 along the Li7 line, positioned on motor 1. As can be seen from figure 3 the maximum temperature along



a *b*

Fig. 3. IR and real spectrum image of motor 1, motor 2 and temperatures along the measured lines: *a* – infrared image; *b* – real image

line Li4, which is positioned on motor 2, is 51.7°C, and the minimum temperature is 43.2°C. The temperature variation along the Li4 line is 8.5°C, and the emissivity is 0.80 along the Li4 line, positioned on motor 2. The maximum temperature along line Li5, which is positioned on motor 2, is 51.5°C and the minimum temperature is 46.3°C. The temperature variation along line Li5 is 5.2°C, and the emissivity is 0.80 along line Li5, positioned on motor 2. The maximum temperature along line Li6, which is positioned on motor 2, is 51.8°C, and the minimum temperature is 44.0°C. The temperature variation along line Li6 is 7.8°C, and the emissivity is 0.80 along line Li6, positioned on motor 2. The maximum temperature along line Li8, which is positioned on motor 2, is 95.9°C, and the minimum temperature is 52.5°C. The temperature variation along the Li8 line is 43.4°C, and the emissivity is 0.80 along the Li8 line, positioned on motor 2. Figure 4 shows the temperature variation along the lines positioned on motor 1 and motor 2.

Table 1

THERMOGRAPHIC MEASUREMENTS FOR MOTOR 1 AND MOTOR 2

Image camera type	FLIR SC640
Li1 Max. temperature	37.9°C
Li1 Min. temperature	31.5°C
Li1 Max. – Min. temperature	6.4°C
Li1 Emissivity	0.80
Li1 Object distance	2.0 m
Li1 Reflected temperature	35.0°C
Li2 Max. temperature	38.5°C
Li2 Min. temperature	31.8°C
Li2 Max. – Min. temperature	6.7°C
Li2 Emissivity	0.80
Li2 Object distance	2.0 m
Li2 Reflected Temperature	35.0°C
Li3 Max. temperature	39.3°C
Li3 Min. temperature	30.6°C
Li3 Max. i Min. temperature	8.7°C
Li3 Emissivity	0.80
Li3 Object distance	2.0 m
Li3 Reflected temperature	35.0°C
Li4 Max. temperature	51.7°C
Li4 Min. temperature	43.2°C
Li4 Max. – Min. temperature	8.5°C
Li4 Emissivity	0.80
Li4 Object distance	2.0 m
Li4 Reflected temperature	35.0°C
Li5 Max. temperature	51.5°C
Li5 Min. temperature	46.3°C
Li5 Max. – Min. temperature	5.2°C
Li5 Emissivity	0.80
Li5 Object distance	2.0 m
Li5 Reflected temperature	35.0°C
Li6 Max. temperature	51.8°C
Li6 Min. temperature	44.0°C
Li6 Max. – Min. temperature	7.8°C
Li6 Emissivity	0.80
Li6 Object distance	2.0 m
Li6 Reflected temperature	35.0°C
Li7 Max. temperature	34.0°C
Li7 Min. temperature	29.9°C
Li7 Emissivity	0.80
Li7 Max. – Min. temperature	4.1°C
Li7 Object distance	2.0 m
Li7 Reflected temperature	35.0°C
Li8 Max. temperature	95.9°C
Li8 Min. temperature	52.5°C
Li8 Max. – Min. temperature	43.4°C
Li8 Object distance	2.0 m
Li8 Emissivity	0.80
Li8 Reflected temperature	35.0°C

In the research carried out in this paper on this machine analysed, it can be noticed that the temperature increases in the range of 34°C – 39.3°C for Motor 1 analysed are considered normal operating temperatures, in normal operation, compared to the temperatures analysed for Motor 2 which are in the range 51.5°C – 95.9°C. The temperature differences analysed for the two motors are due to the improper function of the cooling fan of Motor 2. The difference

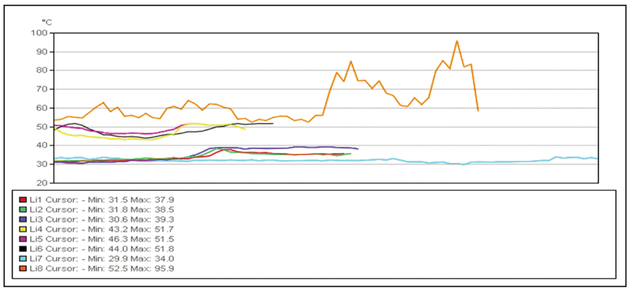


Fig. 4. Temperature variation along the lines positioned on motor 1 and motor 2

in temperature in the fan area between the two motors is 61.9°C as shown in figure 3, a. The differences in temperature along the analysed lines for the two motors are 13°C respectively 13.8°C.

Figure 5, *a* shows the values of minimum and maximum temperatures along the lines Li1, Li2, Li3, and Li7 and the approximation curve of the values for Motor 1 and figure 5, b shows the minimum and maximum temperature values along the lines Li4, Li5, Li6, Li8 and the estimate curve for Motor 2.

In the case of Motor 1, as shown in figure 5, a relation obtained is a polynomial function of degree 5:

$$y = 0.0318x^5 - 0.7757x^4 + 6.7624x^3 - \\ - 25.389x^2 + 39.999x + 10.85 \quad (1)$$

The coefficient of determining R^2 established by the regression [26] procedure is:

$$R^2 = 0.9218 \quad (2)$$

In this case, when the polynomial function [8] regression R^2 has a value higher than 0.9 the mathematical model represents the real situation of the heat distribution on the analysed surfaces of Motor 1, temperature values outside this domain.

In the case of Motor 2 as shown in figure 5, *b* the relation obtained is a polynomial function of degree four:

$$y = 0.3312x^4 - 5.2252x^3 + 27.644x^2 - \\ - 53.897x + 75.602 \quad (3)$$

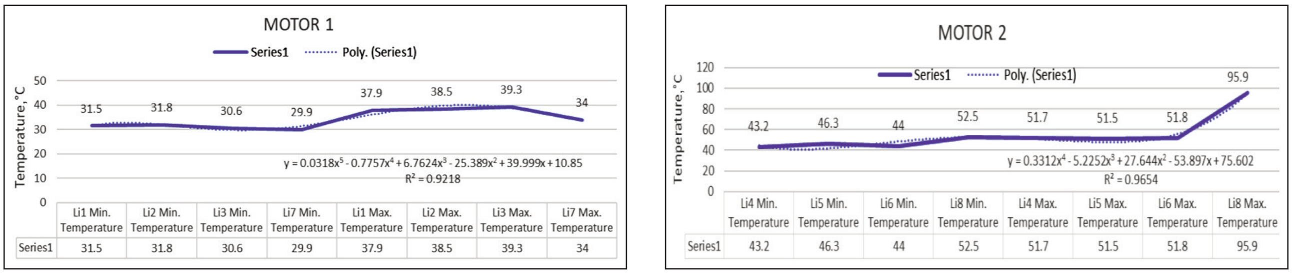
The coefficient of determining R^2 established by the regression procedure is:

$$R^2 = 0.9654 \quad (4)$$

In this case when the polynomial function regression R^2 has a value of less than 0.9 the mathematical model represents less the real situation and the heat distribution on the analysed surfaces of motor 2, temperature values outside this domain.

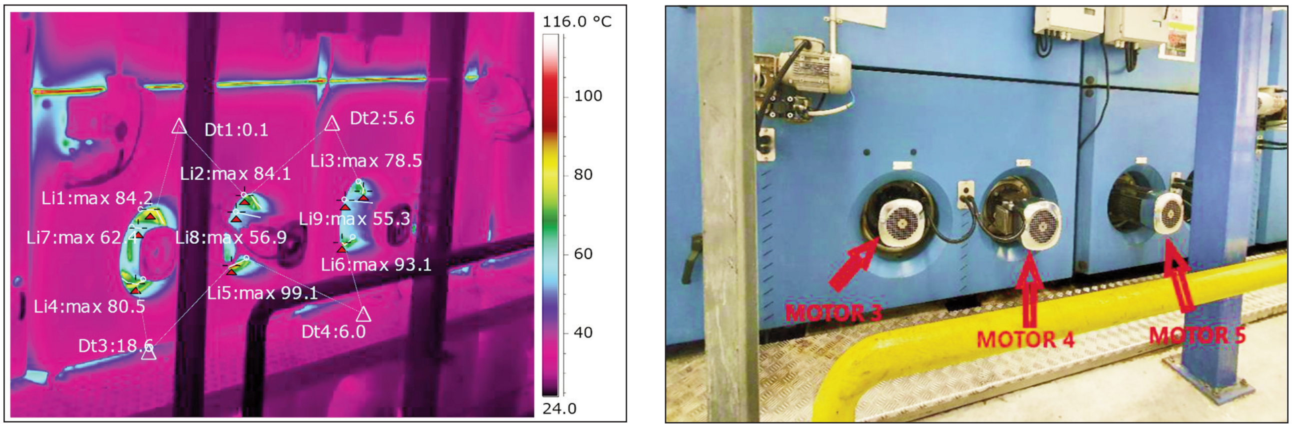
The purpose of the regressions is to predict the evolution of temperatures along the analysed lines outside the measurement range.

In the case of motors 4 and 5 analysed it can be noticed that the maximum temperature along the analysed lines Li5 and Li6 is 99.1°C respectively 93.1°C (table 2). To ensure acceptable operation, it is recommended that the bearings are properly greased for high-temperature operation. Motors 3, 4 and 5 shown in figure 6 are 4.5–5 kW fan motors, their purpose is to aerate the material to dry it (to maintain a



a ***b***

Fig. 5. Temperature variation along the minimum and maximum lines and approximation curves for: *a* – motor 1; *b* – motor 2



a ***b***

Fig. 6. IR and real spectrum image of motor 3, motor 4, motor 5 and temperatures along the measured lines: *a* – infrared image; *b* – real image

Table 2

THERMOGRAPHIC MEASUREMENTS FORMOTOR 3, MOTOR 4 AND MOTOR 5	
Image camera type	**FLIR SC640**
Li1 Max. temperature	84.2°C
Li1 Min. temperature	53.8°C
Li1 Max. – Min. temperature	30.4°C
Li1 Emissivity	0.95
Li1 Object distance	2.0 m
Li1 Reflected temperature	22.5°C
Li2 Max. temperature	84.1°C
Li2 Min. temperature	56.6°C
Li2 Max. – Min. temperature	27.4°C
Li2 Object distance	2.0 m
Li2 Emissivity	0.95
Li2 Reflected temperature	22.5°C
Li3 Max. temperature	78.5°C
Li3 Min. temperature	67.3°C
Li3 Max. – Min. temperature	11.2°C
Li3 Emissivity	0.95
Li3 Object distance	2.0 m
Li3 Reflected temperature	22.5°C
Li4 Max. temperature	80.5°C
Li4 Min. temperature	60.4°C
Li4 Max. – Min. temperature	20.1°C
Li4 Emissivity	0.95
Li4 Object distance	2.0 m
Li4 Reflected temperature	22.5°C
Li5 Max. temperature	99.1°C
Li5 Min. temperature	59.9°C
Li5 Max. – Min. temperature	39.2°C
Li5 Emissivity	0.95
Li5 Object distance	2.0 m
Li5 Reflected temperature	22.5°C
Li6 Max. temperature	93.1°C
Li6 Min. temperature	56.4°C
Li6 Max. – Min. temperature	36.8°C
Li6 Emissivity	0.95
Li6 Object distance	2.0 m
Li6 Reflected temperature	22.5°C
Li7 Max. temperature	62.4°C
Li7 Min. temperature	56.9°C
Li7 Max. – Min. temperature	5.5°C
Li7 Emissivity	0.95
Li7 Object distance	2.0 m
Li7 Reflected temperature	22.5°C
Li8 Max. temperature	56.9°C
Li8 Min. temperature	44.7°C
Li8 Max. – Min. temperature	12.3°C
Li8 Emissivity	0.95
Li8 Object distance	2.0 m
Li8 Reflected temperature	22.5°C
Li9 Max. temperature	55.3°C
Li9 Min. temperature	42.7°C
Li9 Max. – Min. temperature	12.7°C
Li9 Emissivity	0.95
Li9 Object distance	2.0 m
Li9 Reflected temperature	22.5°C

temperature that does not cause damage to the treated material) and their monitoring takes place in real-time in the software, compared to motors 1 and 2 for which the monitoring is not included in the software and therefore requires more attention and is the subject of this research. So, they need separate periodic monitoring and proper operation, considering that these motors (1 and 2) have the role of setting the material on the conveyor chain.
Figure 7 shows the temperature variation along the lines positioned on motor 3, motor 4 and motor 5.

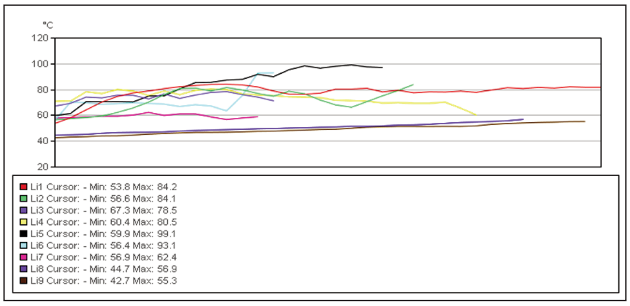


Fig. 7. Temperature variation along the lines positioned on motor 3, motor 4 and motor 5

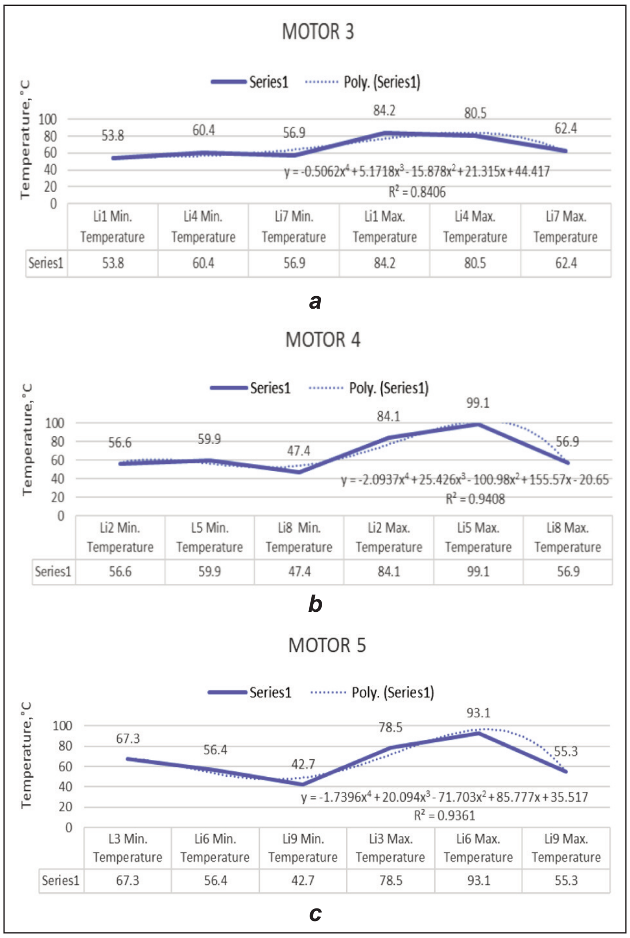


Fig. 8. Temperature variation along the minimum and maximum lines and estimate curves for: *a* – motor 3; *b* – motor 4; *c* – motor 5

In figure 8, the values of minimum and maximum temperatures along the lines Li1, Li4, and Li7 and the approximation curve of the values of Motor 3 are shown, in figure 8, b the values of minimum and maximum temperatures along the lines Li2, Li5, Li8 and the approximation curve of the values of Motor 4 are shown and in figure 8, c are shown the values of minimum and maximum temperatures along the lines Li3, Li6, Li9 and the approximation curve of the values of Motor 5.

In the case of Motor 3, as shown in figure 8, a relation obtained is a polynomial function of degree four:

$$y = -0.5062x^4 + 5.1718x^3 - 15.878x^2 + \\ + 21.315x + 44.417 \tag{5}$$

The coefficient of determining R^2 established by the regression procedure is:

$$R^2 = 0.8406 \tag{6}$$

In this case when the polynomial function regression R^2 has a value of less than 0.9 the mathematical model represents less the real situation and the heat distribution on the analysed surfaces of Motor 3, temperature values outside this domain.

In the case of Motor 4 as shown in figure 8, *b* the relation obtained is a polynomial function of degree four:

$$y = -2.0937x^4 + 25.426x^3 - 100.98x^2 + \\ + 155.57x - 20.65 \tag{7}$$

The coefficient of determining R^2 established by the regression procedure is:

$$R^2 = 0.9408 \tag{8}$$

In this case, when the polynomial function regression R^2 has a value higher than 0.9 the mathematical model represents the real situation of the heat distribution on the analysed surfaces of Motor 4, temperature values outside this domain.

In the case of Motor 4 as shown in figure 8, c the relation obtained is a polynomial function of degree four:

$$y = -1.7396x^4 + 20.094x^3 - 703x^2 + \\ + 85.777x + 35.517 \tag{9}$$

The coefficient of determining R^2 established by the regression procedure is:

$$R^2 = 0.9361 \tag{10}$$

In this case, when the polynomial function regression R^2 has a value higher than 0.9 the mathematical model represents the real situation of the heat distribution on the analysed surfaces of Motor 4, temperature values outside this domain.

DISCUSSIONS

Compared to other papers realized at the international level in which realized thermographic monitoring of motors on different equipment, in the present paper the authors carried out research on the whole technological flow (of mattress material treatment which has a decisive role in ensuring optimal loading with different material treatment solutions according to customer requirements) to plan predictive maintenance activities by different online monitoring methods. If motors 1 and 2 do not work simultaneously and in sync, there is no correct (uniform) wrapping of the treated material on the drum, which can lead to a deformation of the material on it. In addition to the treatments brought to the materials, the machine analysed in this work also has the role of fixing and stabilizing the material through the roller systems and the steam generator. If the two motors (motor 1 and motor 2) do not work properly, during the material treatment process, defects may occur regarding its thermofixing process and a poor load with solutions, due to the difference in the speed of material transport. We can conclude that motors 3, 4 and 5 have the role of ventilation to maintain a constant temperature on the treated material. They have no direct effects on the material because they have real-time temperature monitoring in the software compared to motors 1 and 2 which have the role of stretching and transporting the material, the latter not being monitored in the software. The thermal analysis of the finishing equipment within SC Lava Knitting [27] in Oradea is a very important one (to plan the maintenance activities) because this machine has a huge role in ensuring optimal loading with different material treatment solutions, designed for mattresses, by customer requirements. This paper presents a topic of interest to researchers and practitioners, as it aims to address the issues faced by companies in the field to create a constant technological flow and prevent unexpected engine failures. The authors of the paper recommend regular monitoring of engines with the help of thermography to improve the maintenance and reliability of textile equipment.

CONCLUSIONS

Since there is no universal application for checking the status of a machine, specific methods must be used depending on the characteristics of the monitored machinery. The heating of the analysed motor is due to the operating environment, the authors suggest checking the ventilation holes. The motors analysed in this sizing-finishing machine, are provided with forced air cooling below 15 Hz so therefore it is necessary to cool them forcefully. The operating status of the forced cooling fans must be checked which are mounted separately from the motor housing. The authors propose the installation of thermal insulating pipes that ensure the air intake from the outside of the building where the sizing-finishing machine is and provide a cooler to it. The authors propose solving the problem of motor alignment with the reducer with the means of vibration analysis. At a temperature of over 90°C, there occurs the problem of melting the grease from the bearings, so it is recommended to lubricate the bearings with petroleum jelly appropriate to the thermal operating regime of the motor as well as to periodically remove the lint deposits from the cooling slots of the motor and the suction mouth of the fan for forced air cooling. The mathematical modelling of the results obtained from the thermal analysis of the engines was performed based on the polynomial regression which is used to predict the evolution of the temperatures along the analysed lines outside the measurement range for each engine analysed. In conclusion, thermographic monitoring is an efficient technique for detecting problems that may occur in motors of the textile equipment. In the textile industry, motors are a crucial component in weaving, knitting, finishing, dyeing and printing processes, their performance has a direct impact on the quality and productivity of textile products. Regular monitoring of motors using thermography can help identify potential problems before they become serious, allowing preventive maintenance and improving the reliability and efficiency of textile industry equipment.

ACKNOWLEDGEMENTS

The research was funded by the University of Oradea, within the Grants Competition “Scientific Research of Excellence Related to Priority Areas with Capitalization through Technology Transfer: INO–TRANSFER–UO”, Projects No. 238/2022.

REFERENCES

[1] Alvaro, I.A.H., Israel, Z.R., Arturo, Y.J.C., Roque, O.R., Vicente, D.Q., Arturo, Y.J.C., *Infrared Thermography Smart Sensor for the Condition Monitoring of Gearbox and Bearings Faults in Induction Motors*, In: Sensors, 2022, 22, 16, 6075, https://doi.org/10.3390/s22166075

[2] Mykoniatis, K., *A Real-Time Condition Monitoring and Maintenance Management System for Low Voltage Industrial Motors Using Internet-of-Things*, In: Procedia Manuf., 2020, 42, 450–456, https://doi.org/10.1109/TIE.2003.817693

[3] Banerjee, D., Chattopadhyay., S.K., Suneet, T., *Infrared thermography in material research – A review of textile applications*, In: Indian Journal of Fibre & Textile Research, 2013, 38, 4, 427–437

[4] Gurmeet, S., Anil Kumar, T.Ch., Naikan, V.N.A., *Induction motor inter turn fault detection using infrared thermographic analysis*, In: Infrared Physics & Technology, 2016, 77, 277–282, https://doi.org/10.1016/j.infrared.2016.06.010

[5] Ammer, K., *Diagnosis of raynaud's phenomenon by thermography*, In: Skin Res. Tech., 2006, 2, 182–185

[6] Ng, E.Y.K., Acharya, R., *Remote-sensing infrared thermography*, In: IEEE Eng. Med. Biol., 2009, 28, 76–83

[7] Gold, J.E., Cherniack, M., Buchholz, B., *Infrared thermography for examination of skin temperature in the dorsal hand of office workers*, In: Eur. J. Appl. Physiol., 2004, 93, 245–251

[8] Dragos, P.F., Şuteu, M.D. Rares, P., Buhas, S.D., *Thermal Transfer Analysis for Sports Footwear, for Performance Athletes, during Volleyball Training*, In: Sustainability 2023, 15, 1, 652, https://doi.org/10.3390/su15010652

[9] Budzier, H., Gerlach, G., *Thermal Infrared Sensors: Theory, Optimisation and Practice*, John Wiley & Sons: Chichester, UK, 2011, 328, ISBN 978-0-470-97675-3

[10] Chua, J.H.J., Dyer, A.G., Garcia, J.E., *Hot Shoes in the Room: Authentication of Thermal Imaging for Quantitative Forensic Analysis*, In: J. Imaging, 2018, 4, 21

[11] Maldague, X.P.V., Jones, T.S., Kaplan, H., Marinetti, S., Prystay, M., *Chapter 2: Fundamentals of Infrared and Thermal Testing,* Nondestructive Handbook, ASNT Press: Columbus, OH, USA, 2001, 26–137

[12] Finney, A., *Infrared photography*, In: The Focal Encyclopedia of Photography: Digital Imaging, Theory and Applications; History, and Science, Ed. Elsevier/Focal Press: Burlington, NJ, USA, 2007, 556–562

[13] Puszkarz, A.K., Usupov, A., *The Study of Footwear Thermal Insulation Using Thermography and the Finite Volume Method*, In: Int. J. Thermophys., 2019, 40, 1–14

[14] Baban, M., Baban, C.F., Şuteu, M.D., *Maintenance Decision-Making Support for Textile Machines: A Knowledge-Based Approach Using Fuzzy Logic and Vibration Monitoring*, In: IEEE ACCESS, ISSN 2169-3536, 2019, 7, 7, 83504–83514

[15] Duffuaa, S.O., Raouf, S., *Planning and Control of Maintenance Systems: Modelling and Analysis*, 2nd ed. Cham, Switzerland: Springer, 2015

[16] Kothamasu, R., Huang, S.H., VerDuin, W.H., *System health monitoring and prognostics – A review of current paradigms and practices*, In: Int. J. Adv. Manuf. Technol., 2006, 28, 9–10, 1012–1024

[17] Swanson, L., *Linking maintenance strategies to performance*, In: Int. J. Prod. Econ., 2001, 70, 3, 237–244

[18] Alsyouf, I., Maintenance practices in Swedish industries: Survey results, In: Int. J. Prod. Econ., 2009, 121, 1, 212–223

[19] Bottani, E., Ferretti, G., Montanari, R., Vignali, G., *An empirical study on the relationships between maintenance policies and approaches among Italian companies,* In: J. Qual. Maintenance Eng., 2014, 20, 2, 135–162

[20] Șuteu, M., Indrie, L., Gherghel, S., Timofte, A., *Identifying the points that represent potential defects in embroidery machines using infrared thermography*, In: Industria Textila, 2015, 66,1, 39–42

[21] Șuteu, M.D., Băban, C.F., Băban M., Pancu, R.M., Toth E., *Thermographic analysis of the ricoma 2 head embroidery machine*, In: Annals of the University of Oradea, Fascicle of Textiles, Leatherwork, ISSN 1843-813X, Oradea, Volume XIX, 2018, 2, 99–104

[22] Baban, C.F., Baban, M., Şuteu, M.D., *Using a fuzzy logic approach for the predictive maintenance of textile machines*, In: Journal of Intelligent & Fuzzy Systems, 2016, 30, 2, 999–1006

[23] Șuteu, M.D., Băban, M., Băban, C.F., Derecichei, A.P., Using Anfis for maintenance planning of textile machines, In: Annals of the University of Oradea, Fascicle of Textiles-Leatherwork, ISSN 1843-813X, Oradea, 2020, 21, 1, 123–126

[24] Șuteu, M.D., Băban, C.F., Băban, M., Dragomir, G., Toth E., *Predictive maintenance of the automated sewing machines in textile industry*, In: Annals of the University of Oradea, Fascicle of Textiles-Leatherwork, ISSN 1843-813X, Oradea, 2019, 20, 2, 103–106

[25] Șuteu, M.D., Băban, C.F., Băban M., Toth E., Pancu, R.M., *Maintenance planning of the sewing needles of simple sewing machines*, In: Annals of the University of Oradea, Fascicle of Engineering and Industrial Management, ISSN 1843-813X, Oradea, 2017, 18, 2, 99–102

[26] Stevenson, C., *Tutorial: Polynomial Regression in Excel. faculty staff*, Richmond. Edu., Available at: https://facultystaff.richmond.edu/~cstevens/301/Excel4.html [Accessed on May 2nd, 2023]

[27] *Lava*, Available at: https://www.lavatextiles.com/ [Accessed on March 20, 2023]

Authors:

MARIUS DARIUS ȘUTEU[1], RAREȘ PANCU[2], TIBERIU VESSELENYI[3], GABRIELLA BOHM[1], LILIANA DOBLE[1]

[1]University of Oradea, Faculty of Energy Engineering and Industrial Management,
Department of Textiles-Leather and Industrial Management, 1st University Street, 410087, Oradea, Romania

[2]University of Oradea, Faculty of Management and Technological Engineering, Department of Engineering
and Management, 1st University Street, 410087, Oradea, Romania
e-mail: pancurares@yahoo.com

[3]University of Oradea, Faculty of Management and Technological Engineering, Department of Mechatronics,
1st University Street, 410087, Oradea, Romania
e-mail: vtiberiu@uoradea.ro

Corresponding author:

MARIUS DARIUS ȘUTEU
e-mail: suteu_marius@yahoo.com