

**MONITORIZAREA SI
DIAGNOZA
COMPORTAMENTULUI
DIVERSELOR TIPURI DE
MOTOARE ELECTRICE DE UZ
INDUSTRIAL FOLOSIND
ANALIZA IMAGINILOR
TERMOGRAFICE**

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REZUMAT: In aceasta lucrare autoarea prezinta rezultatele experimentale ale monitorizarii si diagnozei comportamentului diverselor tipuri de motoare de uz industrial folosind analiza imaginilor termografice. Scopul experimentului a fost sa se determine daca comportamentele din timpul functionarii diferitelor motoare electrice in diverse situatii monitorizate cu o camera de termoviziune ofera suficiente date de diagnoza care ar putea ulterior sa fie folosite la diagnosticarea oricarui alt motor de uz industrial in timpul functionarii lui.

CUVINTE CHEIE: monitorizare termica, diagnoza, motoare electrice, analiza imagini termografice.

1. INTRODUCERE

Ideea de baza a acestei lucrari a pornit de la dorinta de a gasi o metoda care sa realizeze o mentenanta predictiva a motoarelor de uz industrial prin monitorizarea functionarii acestora in diverse situatii, pentru a putea prezice un defect inainte de aparitia acestuia si mai ales a cauzelor ce pot surveni in urma aparitiei lui. Un defect [1] face ca

**MONITORING AND DIAGNOSIS
OF THE BEHAVIOR OF
VARIOUS TYPES OF
INDUSTRIAL USE ELECTRIC
ENGINES USING
THERMOGRAPHIC IMAGE
ANALYSIS**

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ABSTRACT: In this paper, the author presents the experimental results for monitoring and diagnosis of the behavior of various types of industrial use electric engines using thermographic image analysis. The purpose of the experiment was to find out if behaviors of different running electric engines and in various situations monitored with a thermovision camera offer enough diagnosis data that could further be used to diagnose any other industrial use electric engine while functioning.

KEY WORDS: thermal monitoring, diagnosis, electric engines, thermographic image analysis.

1. INTRODUCTION

The basic idea of this paper came out of the desire to find a method that would offer predictive maintenance to all industrial use electric engines through their monitoring in various situations in order to be able to predict a fault before it appears and mostly before causes appear. A fault [1] makes that the equipment, in our case electric engines to work in unacceptable parameters. After a while called fault development period, the fault leads to failure which stops the electric

echipamentul, in cazul de fata motorul, sa functioneze la parametri inacceptabili. Dupa un anumit interval de timp numit perioada de dezvoltare a defectului, defectul duce la avarie sau la pana, adica la oprirea functionarii motorului si implicit a ansamblului in care este montat.

Teoretic, pentru a putea prezice aparitia defectului sau a avariei, se pot urma primele doua nivele (nivelul 1 format din 1. si 2., iar nivelul 2 din a., b. si c.) ale taxonomiei de metode de predictie [2] de mai jos, restul nivelelor fiind ocupate de metode particularizate pentru fiecare echipament monitorizat:

Predictia avariei:

1. nu evaluam starea curenta – aici metoda se bazeaza pe fiabilitate
2. evaluam starea corecta
 - a. aparitia de avarii
 - b. efectele secundare ale aparitiei defectelor
 - c. modul de manifestare al defectelor

Dupa cum se poate observa in figura 1, prezicerea avariei poate declansa o actiune preventiva pentru a evita avaria sau poate pregati pentru actiunea de reparare (dupa avarie) [2].

engine and also the assembly it is in.

In theory, to predict the fault or failure, one can follow the first two levels (level 1 of 1. and 2. and level 2 of a., b., and c.) of the prediction methods taxonomy [2] below, the rest of the levels being kept for the particular methods used for equipment that is being monitored:

Fault prediction:

1. not evaluating current state – method based on reliability
2. evaluating current state
 - a. occurrence of failures
 - b. side-effects of faults
 - c. manifestation of faults.

As can be seen in figure 1, predicting the fault can trigger a preventive action in order to avoid the failure or can prepare for repairing action (after failure takes place) [2].

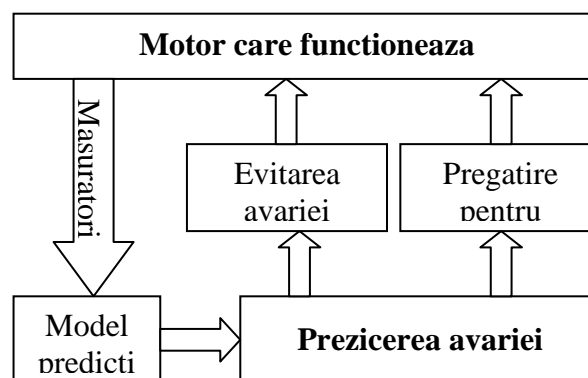


Figura 1. Managementul proactiv al defectelor

Figura 1. Proactive fault management

De asemenea, s-a dorit a se gasi un raspuns la intrebarea: “Rezultatele oferite de diagnosticarea unui tip de motor ar putea

Also, an answer to the question “Could the results offered by the diagnosis of an electric engine type contribute to predictive

contribui la mentenanta predictiva a oricarui motor de uz industrial?”. Raspunsul a fost cautat mai intai in rezultatele oferite de monitorizarea catorva tipuri de motoare si in diverse situatii cu o camera de termoviziune.

2. MONITORIZAREA FUNCTIONARII MOTOARELOR

Am stabilit mai sus ca se poate prezice deteriorarea unui echipament electric sau energetic pentru a se putea remedia cauza inaintea aparitiei efectului (in cele mai multe cazuri, aparitia unei probleme este precedata de fenomenul de incalzire locala, mult peste valoarea normala inscrisa in datele tehnice ale echipamentului) [3]. Tocmai din acest considerent am ales ca echipament de monitorizare pentru acest experiment o camera de termoviziune sau termografica Flir Systems, model T200, ca in figura 2. De asemenea, se stie din [4] ca monitorizarea cu camera de termoviziune este o tehnica de monitorizare neinvaziva si nedistructiva.



Figura 2. Camera de termoviziune Flir T200
Figure 2. Thermovision camera Flir Systems T200

O camera de termoviziune absoarbe energia termica sau infrarosie (invizibila ochiului uman) emisa de suprafata unui obiect monitorizat si o transforma intr-o imagine termica sau termograma. Ce apare in imaginea termica colorat de la galben la rosu spre alb reprezinta temperaturi ridicate, alb fiind maxima, iar negru – albastru reprezinta temperaturi joase, negru fiind minima [5].

maintenance of any other industrial use electrical engine?” was desired to be found. The answer was first searched in the results offered by the monitoring of some types of electric engines and in different situations with a thermovision camera.

2. MONITORING RUNNING ELECTRIC ENGINES

There is established above that deterioration of an electric or energetic equipment can be predicted in order to remedy the cause before effect appears (in most cases, when a problem appears it is followed by a local heating phenomenon, much over the normal value that is written in equipment’s data sheet) [3]. Because of that we chose as monitoring equipment a thermovision camera Flir Systems T200, as in Figure 2. Also, it is known from [4] that monitoring with a thermovision camera is a non-invasive and nondestructive technique.

A thermovision camera absorbs thermal or infrared energy (invisible to the human eye) that is emitted by the surface of a monitored object and transforms it into a thermal image or a thermogram. What appears in the thermal image from yellow to red and white represent high temperatures, white being the maximum, and black-blue represent low temperatures, black being the

Imaginile termice sunt o modalitate simplă de a identifica diferențe de temperatură aparentă în echipamentele industriale (motoare, în cazul de față) monitorizate, comparându-le cu condițiile lor normale de funcționare.

Cu camera de termoviziune observăm carcasa (suprafața exterioară) motorului. Știm din [6] că pentru fiecare motor există o temperatură de funcționare normală, care de obicei este însemnată în datele lui tehnice, sau pe o placă înscrisă și atașată carcasei. Temperatura aparentă normală este între 49... 60°C și depinde foarte mult de condițiile de mediu. Când creșterea temperaturii depășește valoarea de 60°C, înseamnă că acel motor se confruntă cu o problemă. Din moment ce majoritatea motoarelor de aceeași dimensiune funcționează sub aceeași sarcină, devine foarte simplu să identifici comparativ motoare “fierbinti” și să iei măsuri corecte.

Problemele la motoare sunt identificate de obicei comparând temperatura la suprafața motoarelor similare, lucrând în aceleași condiții. Suprincalzirea apare ca „puncte calde” într-o imagine termică și sunt de obicei găsite prin comparație cu echipamente similare.

În continuare se vor analiza atât echipamente similare supuse unor condiții diferite de funcționare, cât și echipamente diferite în condiții diferite de funcționare.

Cazul 1. Monitorizarea funcționării unui motor asincron (carcasa acestuia) – **Încercare în gol** până când se atinge echilibrul termic, adică egalitatea dintre cantitatea de căldură dezvoltată de curent în mașină și cantitatea de căldură evacuată în mediul ambiant. În acest regim, suprafața exterioară a carcasei are temperaturi stabilizate. Motorul are datele tehnice:

- putere $P=4\text{kW}$,

minimum [5].

Thermal images are a simple way to identify apparent temperature differences in the monitored industrial equipments (electric engines), comparing them to the normal functioning conditions.

With the thermovision camera we observe the housing (exterior surface) of the electric engine. We know from [6] that for every electric engine there is a normal functioning temperature, which is written in its technical data sheet or on a board attached to the housing. Normal apparent temperature is between 49... 60°C and depends a lot of the environmental conditions. When the temperature rises over 60°C, it means that the electric engine has a problem. Since most electric engines of the same dimensions work under the same load, it becomes very simple to compare “hot” engines and to take proper measures.

Problems at engines are usually identified comparing the surface of similar engines, working in the same conditions. Overheating appears as “hot spots” into a thermal image and are usually found by comparison with similar equipments.

Further on will be analyzed similar equipments under different conditions, but also different equipments in different functioning conditions.

Case 1. Monitoring the functioning of an asynchronous electric engine (its housing) – **Empty attempt** until thermal equilibrium is reached, meaning heat quantity developed by the current inside to be equal to the heat quantity released to the environment. In this regime, the exterior surface of the housing has stabilized temperatures. The electric engine has the characteristics:

- power $P=4\text{kW}$,

- nominal voltage $U_n=380\text{V}$,

- current in stator circuit $I_s=10\text{A}$ and

- tensiune nominala $U_n=380V$,
- curentul in circuitul statoric $I_s=10A$
- si in circuitul rotoric $I_r= 20A$,
- turatia $n=3000$ rotatii/min.

La aceasta incercare, pe camera am setat parametrii astfel: temperatura ambianta: $19,6^{\circ}C$, distanta fata de obiect: 2m, umiditate 50%, emisivitate material: 0.96.

In figura 3. de mai jos este imaginea termica a motorului la temperatura mediului ambiant, care contine informatii termice (ex.:temp medie a ariei $19,1^{\circ}C$), cat si imaginea sa in vizibil:

- in rotor circuit $I_r= 20A$,
- speed $n=3000$ rotations/min.

At this attempt, on the camera I set the parameters: environmental temperature: $19,6^{\circ}C$, distance to object: 2m, humidity 50%, emissivity: 0.96.

In figure 3 below is the thermal image of the electric engine at environmental temperature which contains thermal information (e.g. average temperature of the area: $19,1^{\circ}C$), and also it image in visible:

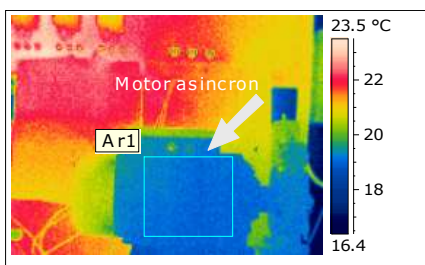


Figura 3.a. Motor in infrarosu la temperatura mediului; b.Motorul in vizibil
Figure 3.a. Electric engine in infrared –environmental. temp; b.Electric engine in visible

Am alimentat motorul la o tensiune de 380V printr-un reostat cu pornire in trepte. Am preluat 18 valori si 8 poze (ex. figurile 4, 5, 6) la intervale de timp diferite, cu ajutorul carora am trasat curba de pornire, anume temperatura maxima de pe suprafata carcasei motorului in functie de timp (figura 17). Se poate observa din termograme cum in aria definita se maresc zona alba, ceea ce indica cresterea temperaturii pe suprafata delimitata.

I powered the engine to 380V through a rheostat which starts in steps.

I took 18 values and 8 images (e.g. figures 4, 5, 6) at different time moments, with the help of which I drawn the starting or heating curve, meaning maximum temperature on the housing's surface function of time (figure 17). Thermograms show that in the defined surface, white area increases, meaning that temperature increases.

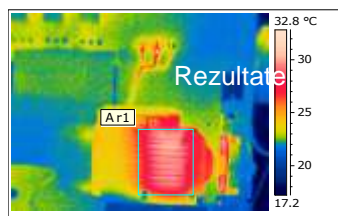


Figura 4.
Figure 4.

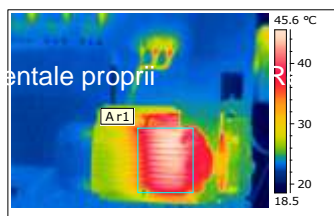


Figura 5.
Figure 5.

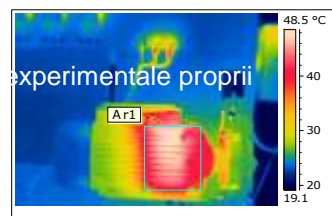


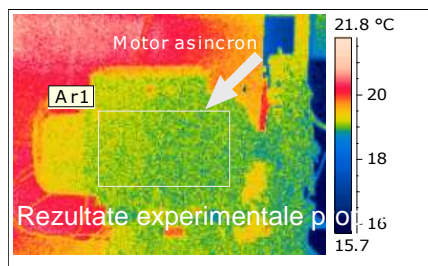
Figura 6.
Figure 6

Cazul 2. Monitorizarea functionarii Case 2. Monitoring the same engine as

aceluiasi motor asincron – **Incercare in gol fara racire**

La aceasta incercare, pe camera am setat urmatoorii parametri: temperatura ambianta: 19,5°C, distanta fata de obiect: 2m, umiditate 50%, emisivitate material: 0,96.

In figura 7. de mai jos este imaginea termica a motorului la temperatura mediului ambiant, care contine informatii termice (ex.:temp medie a ariei 19°C), cat si imaginea sa in vizibil:



above – **Empty attempt without cooling**

In this attempt, I set the following parameters: environmental temperature: 19,5°C, distance to object: 2m, humidity 50%, emissivity: 0.96.

In figure 7. below is the thermal image of the electric engine at environmental temperature, which contains thermal information (e.g. average temperature in area of 19°C), as its visible:



Figura 7.a. Motor in infrarosu la temperatura mediului; b. Motorul in vizibil
Figure 7.a. Electric engine in infrared –environmental. temp; b. Electric engine in visible

Am alimentat motorul la o tensiune de 380V printr-un reostat cu pornire in trepte, inasa de data aceasta am detasat elicea de la sistemul de ventilatie al motorului pentru a simula o defectare a sistemului de ventilare. Am preluat 41 de poze (ex. figurile 8,9,10 si 11) la intervale de timp diferite cu ajutorul carora am trasat curba de pornire din figura 17, anume temperatura maxima de pe suprafata carcasei motorului in functie de timp.

I powered the engine to 380V through a rheostat which starts in steps, but this time I detached the propeller from the ventilation system of the electric engine to simulate a fault in the ventilation system. I took 41 images (e.g. figures 8,9,10 and 11) at different time moments with the help of which I drawn the starting curve in figure 17, namely maximum temperature of the housing’s surface function of time.

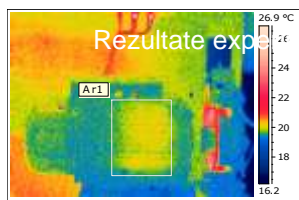


Figura 8.
Figure 8.

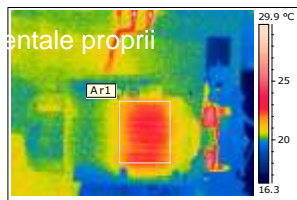


Figura 9.
Figure 9.

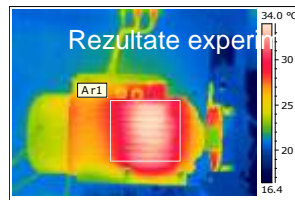


Figura 10.
Figure 10.

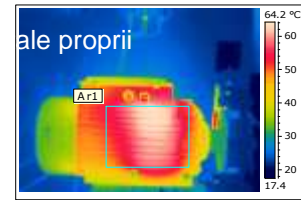


Figura 11.
Figure 11.

Cazul 3 Monitorizarea functionarii a doua motoare identice (carcasa acestora) cu urmatoarele date tehnice:

- putere P=0,87kW,

Case 3 Monitoring the functioning of two identical engines (their housing) with the characteristics:

- power P=0,87kW,

- tensiune nominala $U_n=220V$,
- turatia $n=1500$ rotatii/min.

Unul din ele este in sarcina, iar celalalt are sarcina decuplata, si am monitorizat timp de 15 minute pornirea (evolutia temperaturii pe aceasta perioada), dupa care am oprit alimentarea.

In figura 12 se pot observa cele doua motoare.

- nominal voltage $U_n=220V$,
- speed $n=1500$ rotations/min.

One of them is in load, and the other one has the load decoupled and I monitored for 15 minutes the start (evolution of its temperature over this period) and then I stopped the supply.

In figure 12 the two engines can be seen.

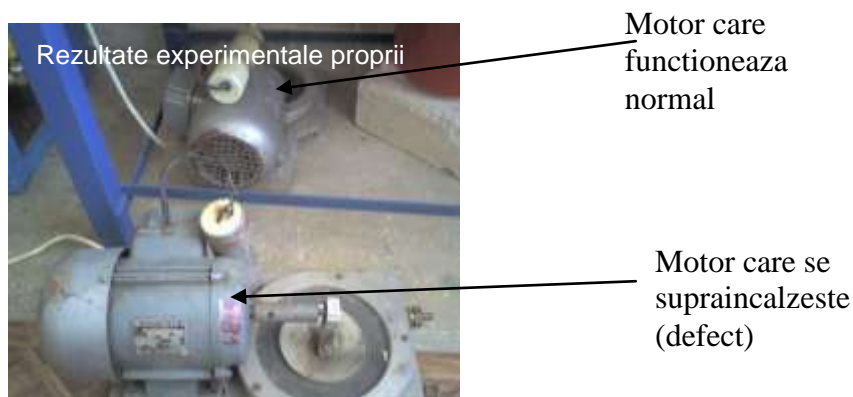


Figura 12.
Figure 12.

In figura 13 si figura 14 sunt termogramele celor doua motoare inainte de a le porni, la temperatura mediului ambiant de $16^{\circ}C$:

In figures 13 and 14 are the thermograms of the two engines before running, at environmental temperature of $16^{\circ}C$:

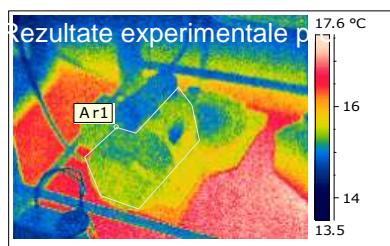


Figura 13 Motor inainte de a fi alimentat

Figure 13 Electric engine before running

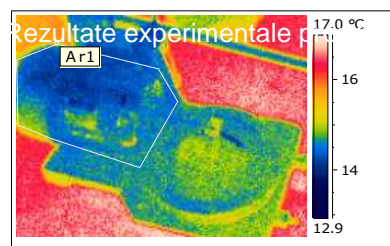


Figura 14 Motor defect inainte de a fi Alimentat

Figure 14 Faulty electric engine before running

In continuare vor fi prezentate cateva termograme (figurile 15 si 16) ce reprezinta incalzirea, puse in paralel pentru cele doua motoare pentru a evidentia viteza de crestere a temperaturii pentru cel defect (figura 16) comparativ cu cel care functioneaza normal (figura 15), cel defect atinand un maxim de aproape $60^{\circ}C$ in 15 minute, pe cand celalalt

Further on will be some thermograms in parallel (figures 15 and 16) which represent the heating of the two engines in order to point out the speed of temperature rise for the faulty engine (figure 16), compared to the one that functions normally (Figure 15), the faulty one reaching a maximum of almost $60^{\circ}C$ in 15 minutes, when the other

de doar 27,4°C în același timp. Și pentru acest caz s-a trasat curba de pornire în figura 18.

of only 27,4°C in the same time. For this case also a starting curve was drawn in figure 18.

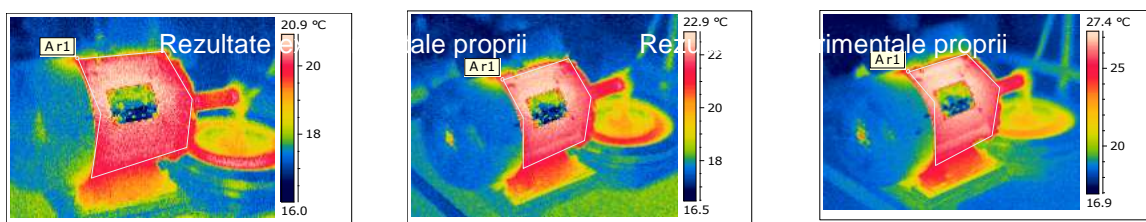


Figura 15. Termograme reprezentând încălzirea motorului ce funcționează normal
Figure 15. Thermograms representing heating of the normal functioning engine

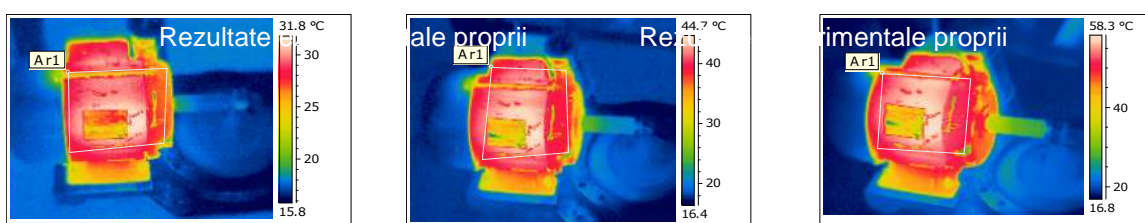


Figura 16. Termograme reprezentând încălzirea motorului defect
Figure 16. Thermograms representing heating of the faulty electric engine

3. DIAGNOZA

Studiind cele 3 cazuri prezentate anterior, putem realiza o diagnoză în felul următor:

Cazul 1

Motorul ajunge în 96 minute de la temperatura mediului în care se regăsea de 19,5°C la temperatura de 49°C, ceea ce demonstrează o funcționare în limite normale.

Cazul 2

Pornind același motor din Cazul 1 care are inițial temperatura de 19,5°C, va ajunge după 96 minute (aproximativ o oră și jumătate) la temperatura de 65,5°C. Aceasta depășește cu mult temperatura nominală de funcționare, care este între 40-50°C. Acest lucru se datorează lipsei ventilației cu care a fost prevăzut.

Cazul 3

Doi motoare identice, aflate în condiții identice sunt pornite în același timp. În 15 minute de observație, unulia îi crește temperatura cu 30°C mai mult decât celuilalt – sarcina decuplată.

3. DIAGNOSIS

Studying the 3 cases presented above, we can make a diagnosis as follows:

Case 1

Electric engine goes in 96 minutes from environmental temperature of 19,5°C to 49°C, which proves a functioning in normal limits.

Case 2

When we run the same electrical engine in Case 1 with initial temperature of 19,5°C, in 96 minutes (almost an hour and a half) it will reach 65,5°C. This exceeds a lot its nominal functioning temperature which is between 40 and 50°C. This happens because of lack of ventilation.

Case 3

Two identical engines, being in the same conditions, are started in the same. In 15 minutes of observation, one will be with 30°C hotter than the other because its decoupled load.

For cases 1 and 2 we have the starting

Pentru cazurile 1 si 2 avem curbele de pornire trasate in figura 17, iar pentru cazul 3, curbele de incalzire sunt trasate in figura 18.

curves in figure 17, and for case 3, the starting curves are drawn in figure 18.

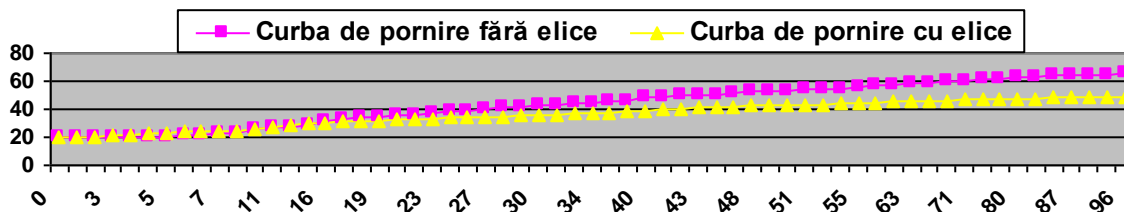


Figura 17.
Figure 17.

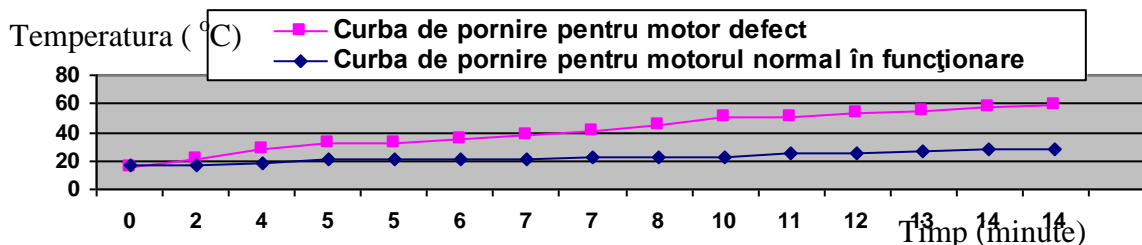


Figura 18.
Figure 18.

4. CONCLUZII

Imaginile termice sunt o modalitate simpla de a identifica diferente de temperatura aparenta in procesele/sistemele industriale, comparandu-le cu conditiile lor normale de functionare.

Din cele 4 grafice situate in figurile 17 si 18 rezultate din cele 3 cazuri, deduc:

- doua situatii in care motoarele par sa functioneze in conditii normale (in 96 minute motorul din Cazul 1 ajunge de la temperatura de la 19,5°C la 49°C, iar in 15 minute motorul care nu e defect din Cazul 3 ajunge de la 16,7°C la 27,4°C) si
- doua situatii in care temperatura normala de functionare a unui motor e depasita (in Cazul 2 motorul fara ventilatie ajunge de la 19,5°C la 65,5°C in 96 min si in Cazul 3 motorul cu sarcina decuplata ajunge de la

4. CONCLUSIONS

Thermal images are a simple way to identify apparent temperature differences in the industrial processes/systems, comparing them with their normal functioning conditions.

From the 4 curves in figures 17 and 18 that are resulted from the 3 cases, I deduce:

- two situations in which engines seem to work in normal conditions (in 96 minutes engine in Case 1 reaches from 19,5°C to 49°C, and in 15 minutes engine not faulty in Case 3 reaches from 16,7°C to 27,4°C) and
- two situations in which normal functioning temperature of an electric engine is exceeded (in Case 2 engine with no ventilation reaches from 19,5°C to 65,5°C in 96 minutes and in Case 3 engine with uncoupled load reaches from 15,9°C to

15,9⁰C la 58,3⁰C in 15 min).

In aceste ultime doua situatii, vazand doar graficele nu pot sti cauza care duce la cresterea temperaturii. Pot concluziona doar ca temperatura imi creste peste limitele normale. Aceasta concluzie conduce la ipoteza ca diagnosticul unui motor in stare anormala de functionare (defect) nu-mi poate indica si defectul, deci scopul experimentului, anume acela de a determina daca comportamentele din timpul functionarii diferitelor motoare monitorizate cu o camera de termoviziune ofera suficiente date de diagnoza care ar putea ulterior sa fie folosite si la diagnosticarea oricarui alt motor in timpul functionarii lui a fost atins, si anume datele oferite de diagnosticarea unui motor nu sunt suficiente pentru a face o generalizare, si in niciun caz la determinarea cauzei defectarii, deoarece doua cauze diferite pot duce prin analiza termografica la acelasi grafic. Stim ca e defect, dar nu stim de ce.

58,3⁰C in 15 minutes).

In the last two situations, seeing only the graphics I cannot know the cause that leads to temperature increase. I can only conclude that temperature increases over normal limits. This leads to the hypothesis that the diagnosis of an electric engine in abnormal state of functioning (faulty) cannot show the fault, so the purpose of the experiment, meaning that to determine weather behaviors during functioning of various electrical engines with a thermovision camera offers enough diagnosis data which could further be used to diagnose any other type of electric engine during functioning was reached, namely that the data offered by diagnosing an electric engine are not enough to generalize, and they could not lead to determining the cause of failure, because two different causes may lead to the same graphic through thermographic. We know it's out of order, but we don't know why.

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