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CORRECTION OF INFLUENCES ON THERMOGRAPHIC MEASUREMENTS FOR NON-CONTACT TEMPERATURE MEASUREMENT USING INFRARED THERMOGRAPHY

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ABSTRACT

The diagnostics failures of monitoring the condition of rotation machinery in the industry are considered very significant to ensure the efficiency and safety of production. However, many serious malfunctioning to the machine could easily occur because of these failures, thus, a huge shortage in production. In this domain, In fact, the most important installation faults lead to an increase of temperature in specific areas. Infrared Thermography is a technique that has been used regularly as a predictive device for the maintenance of electrical installations. It is used around the field in order to evaluate the condition of electrical systems and equipment. This article presents information about issues that demand a specific focus during thermal tests of induction motor. Which are presented as errors that could be made at the testing phase, and especially the descriptions of the influences of parameters, on Thermographic measurements that are obtained by a conversion of raw data to digital data by the use of Flir Tools Software.

Keywords: *Thermography Camera, Moteur Asynchrone, Powder Brake, Effect Of Factors, Temperature Measurement, Thermal Image.*

1. INTRODUCTION

Nowadays many existing industrial induction motors fault diagnosis techniques depend on the analysis of quantities like currents or vibrations [1]. Vibration-based condition monitoring is also spread in the industry, due to its ability to diagnose many failures with a mechanical origin [2]-[3]. Yet, it often requires the installation of sensors and transducers, which is not always a possible option without perturbing the operation of the machine. In any case, neither current nor vibration analysis enables the diagnosis of all possible failures occurring in induction motors. There are some faults (stator short-circuits) which are difficult to be diagnosed with any of the previous quantities, while other (bearing failures, very common in induction motors) could be detected by monitoring vibration signals which, as commented above, are not always available [4]-[5]-[6]-[7].

In this context, infrared thermography plays the important role of identifying and analyzing thermal anomalies for condition monitoring of machines. Infrared thermography works as follows, it measures the distribution of radiant thermal energy (heat) emitted from a target surface and converts the latter to a surface temperature map or thermogram. In thermography, a thermal imaging infrared camera is used to scan, monitor and detect the infrared emissions from the surface and generate thermal patterns or uneven heat distribution of the scanned area. These scanned images are very convenient in detecting incipient fault and deterioration in the equipment caused by overheating due to defect [8]-[9]-[10].

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This article provides information about issues that require specific focus during thermal tests of induction motor. Which are presented as errors that could be possibly made at the testing phase, and especially the descriptions of the influences of parameters, on thermographic measurements that are obtained by a conversion of raw data to digital data by the use of Flir Tools Software? All the measurements performed at the technological platform PFT2M, Industrial Engineering Laboratory and Mechanical Production of the ENSA-Department of Industrial in Oujda.

2. THEORETICAL BACKGROUND

The infrared thermographic camera can capture a thermal pattern's image as well as be used in different temperature ranges depending on the emissivity of the surface. A thermogram then is the thermographic digital image which is captured by the camera. Every pixel of a thermogram has an exact temperature value, and the contrast of the image is derived from the differences in temperature of the object surface [11]. It can occur in levels of gray. The color assignment for each degree of temperature is based on a palette of colors with which it is allowed to view the temperature of the object. In addition Segmentation is capable of analyzing a specific hot spot through a two-dimensional signal that is provided by the infrared thermographic analysis.

The relationship in which Infrared thermography exploits the correlation between the temperature of a surface and also the IR energy which is emitted by the surface is here described by Stefan's Law [12]:

$$W_{BB}(\lambda, T) = \sigma T^4 \quad (1)$$

Yet, it radiates a portion of it, characterized by its emissivity

$$W_{GB}(\lambda, T) = \sigma T^4 \quad (2)$$

The precision of the object temperature which is estimated by the thermographic camera is usually tightly linked to the accuracy of evaluation of input parameters. The emissivity value of the object needs to be determined accurately since it is the most important parameter [13]-[16].

3. SOFTWARE OF THERMAL DATA

FLIR TOOLS is the image processing tool that helps us extract the temperature values that are registered on a Flir image file which allows us to analyze the raw data recorded by infrared camera and convert them into digital data used in the validation process. Conversion errors are at the order errors due to a multiplication of 64 bits which remain negligible. The following figure.1 shows us a preview of FLIR Tools Software.

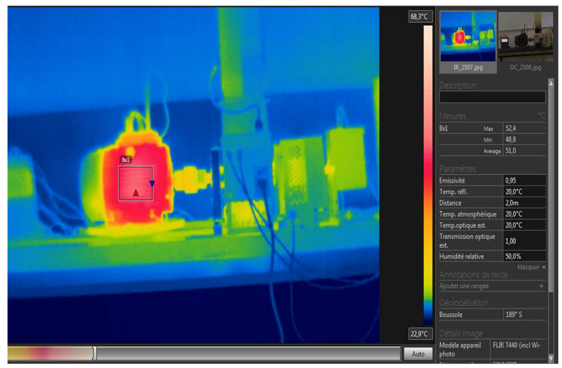

FIGURE.1. Software to analyze data

4. EFFECT OF FACTORS

Temperature of the atmosphere: can modify the actual temperature of an object. By definition this is the temperature of the air between the camera and the object of interest [15].

Reflected temperature: can change the actual temperature of object. In a case the background has more emissivity than the target object. Then infrared camera will see the background hotter than the target. In another case where the target object has more emissivity, then the latter shall be hotter than the background [14]-[15].

Relative humidity: is the amount of water in the air at any particular temperature relative to the saturation level. It also has minimal effect on object temperature measurement and increases with the object temperature [14]-[15].

5. EXPERIMENT AND MEASUREMENTS

5.1. Experimental setup

Figure.2. was constructed in the technological platform PFT2M, Industrial Engineering Laboratory and Mechanical Production of the ENSA-Department of Industrial in Oujda. Figure.3 demonstrates a view of the experimental set-up with all the measurement devices. It is composed of a three-phase motor group with an encoder fixed on a baseplate. The motor controller

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consists of a frequency converter destinated to adjust progressively the running speed. In addition of having a running speed indicator and an indicator of the power absorbed by the motor.

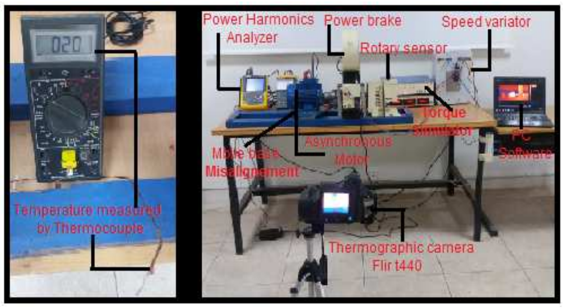

Figure.2 Experimental mounting.

5.2. Experimental procedure

In this experiment, Table.1 lists the main specifications of the thermal camera. The thermographic system communicates with PC which is later processed in the suitable analyzing software. In this work presented the temperature of the windings in a 3-phase motor realized under different load conditions (Figure.1). The technical specifications of the motor are shown in Table.2.

Table.1. Technical characteristics of the Thermographic camera used in this paper

Description	**Value**
Model Name	Flir t440
Temperature measuring range	-20 ^{0}C to 1200 ^{0}C
Emissivity	Correction variable from 0.01 to 1.0 or selected from list of materials
Image frequency	60Hz
Spectral range	7.5 to 13um
Detector	Focal plane array uncooled microbolometer,320 x 240 pixels
Thermal sensitivity	<0.045°C at 30°C

Table.2. Parameters of Induction motor

Parameter	**Value**
Rated Power	0.55 kW
Rated power factor	0.73
Rated Speed	1360 RPM
Power Supply	Three phase 230/400 V 50 Hz
Maximal torque	3.5Nm

Powder brake principle: The DC current injected into the brake coil creates a field which causes the magnetic powder placed in the air gap to agglomerate. The braking torque is proportional to the field current alone; in particular it is independent of the speed of rotation. Waste heat is eliminated by forced ventilation. A circuit breaker cuts the field current in the event of the brake overheating. This brake is always mounted in balance so that it can be equipped with a static sensor with a strain gauge. Listed in Table.3 are the main specifications of the Powder brake are.

Table.3. Technical characteristics of brake settings

Parameter	**Value**
Max torque	65Nm
Weight	21kg
Voltage/Current max for blocking	10V / 0.5A

The thermal images are shown in Figure.3 which carrying only visual inspection of machine condition. Figure.4. shows the data structure from Tools software to analyze data in Celsius scale which has been processed for diagnosis of the frame motor after 60 minutes.

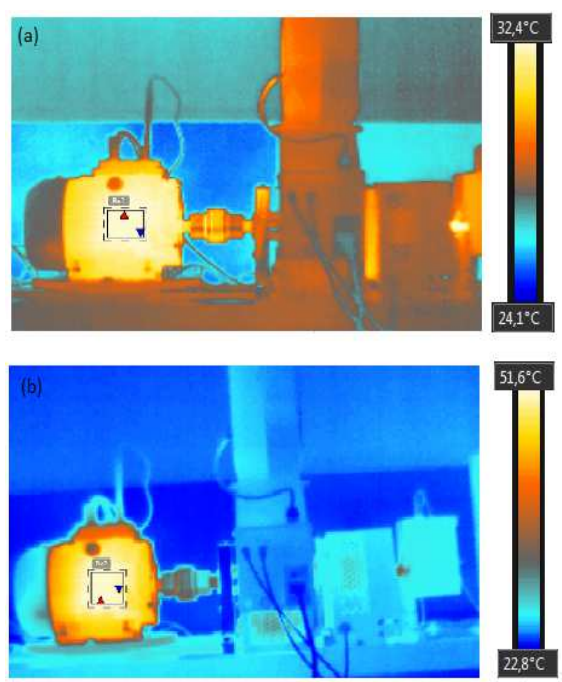

Figure.3. (a) The thermal image of the frame motor after 60 minutes of operation for without load, (b) The thermal image of the frame motor after 60 minutes of operation for full load with the braking torque [2.5Nm].

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(a)

32,24	32,322	32,41	32,4	32,444	32,507	32,332	32,555	32,618	32,512	32,517	32,536	32,521
32,118	32,22	32,201	32,337	32,269	32,366	32,356	32,322	32,415	32,371	32,492	32,269	32,298
32,186	32,356	32,429	32,356	32,449	32,444	32,551	32,555	32,565	32,541	32,56	32,541	32,541
32,41	32,351	32,381	32,487	32,463	32,521	32,565	32,57	32,56	32,585	32,541	32,546	32,575
32,176	32,332	32,337	32,327	32,347	32,395	32,415	32,497	32,327	32,468	32,376	32,439	32,332
32,186	32,317	32,279	32,342	32,361	32,478	32,434	32,512	32,439	32,439	32,507	32,371	32,366
32,317	32,361	32,351	32,405	32,415	32,521	32,405	32,502	32,546	32,575	32,449	32,497	32,531
32,337	32,351	32,371	32,395	32,497	32,468	32,517	32,541	32,551	32,517	32,555	32,618	32,449
32,249	32,308	32,313	32,322	32,361	32,342	32,415	32,434	32,356	32,507	32,42	32,41	32,259
32,249	32,376	32,386	32,468	32,439	32,434	32,487	32,536	32,458	32,575	32,507	32,41	32,366
32,366	32,39	32,546	32,439	32,531	32,546	32,517	32,526	32,512	32,589	32,618	32,444	32,487
32,274	32,298	32,376	32,327	32,497	32,444	32,39	32,347	32,468	32,434	32,497	32,434	32,453
32,356	32,473	32,531	32,517	32,57	32,58	32,565	32,565	32,618	32,58	32,58	32,531	32,483
32,42	32,463	32,41	32,381	32,541	32,589	32,492	32,555	32,551	32,502	32,497	32,468	32,429
32,264	32,303	32,313	32,444	32,347	32,293	32,512	32,487	32,536	32,366	32,405	32,473	32,356

(b)

51,245	51,457	51,78	51,863	51,917	51,933	51,9	52,004	52,033	51,818	51,722	51,644	51,328
51,722	51,826	51,884	51,954	52	52,024	52,132	52,008	52,07	51,793	51,536	51,353	51,22
51,254	51,482	51,548	51,499	51,416	51,416	51,399	51,37	51,299	51,312	51,345	51,15	50,971
51,254	51,432	51,702	51,801	51,971	51,983	52,103	52,103	52,062	52,024	51,805	51,735	51,428
51,892	52,016	52,062	52,239	52,198	52,231	52,235	52,218	52,181	52,066	51,834	51,569	51,349
51,652	51,764	51,652	51,756	51,772	51,615	51,627	51,631	51,366	51,266	51,096	51	50,787
51,42	51,424	51,627	51,776	51,83	51,867	51,88	51,851	51,995	51,797	51,619	51,478	51,229
51,847	51,925	52,074	52,09	52,206	52,206	52,214	52,173	52,086	51,995	51,789	51,503	51,378
51,847	51,95	52,074	52,095	52,095	51,917	51,822	51,677	51,445	51,42	51,258	51,058	50,896
51,337	51,594	51,532	51,623	51,805	51,611	51,652	51,685	51,648	51,453	51,445	51,237	51,05
51,714	51,896	51,917	52,103	52,119	52,09	51,975	51,971	51,925	51,714	51,474	51,287	51,245
51,954	52,099	52,19	52,111	52,123	52,152	52,107	52,049	51,95	51,693	51,403	51,25	51,075
51,565	51,735	51,83	51,814	51,797	51,842	51,971	51,925	51,884	51,735	51,602	51,474	51,333
51,967	52,119	52,165	52,206	52,313	52,354	52,342	52,35	52,326	52,086	51,929	51,756	51,478
51,942	52,128	52,152	52,231	52,223	52,128	52,07	52,049	52,041	51,776	51,495	51,262	51,216

Figure.4. Temperature in Celsius at each pixel of Thermal images, (a) Bx1 the motor frame after 60 minutes of operation for without load, (b) Bx2 the motor frame after 60 minutes of operation for full load with the braking torque [2.5Nm].

Region	Temperature $[{}^{0}C]$	
Bx1	Max	32,6
	Min	31,9
	Average	32,9
Bx2	Max	52,2
	Min	51,0
	Average	51,7

Table.4 Temperature of each region

6. RESULTS

In order to measure the temperature distribution on the body of electrical machines in an accurate way, it is necessary to separate the influence of target sources from disturbances that have to be compensated.

*Table.5. the atmospheric temperature and relative humidity influence on surface temperature measurements for zero load after **10** minutes.*

Relative humidity [%]	**Maximum measure temperature** $T_{\max}[{}^{0}C]$
20%	33.69
30%	33.91
40%	34.14
50%	34.38
75%	34.66
90%	34.92
100%	35.17
Atmospheric temperature $T_{atm}[{}^{0}C]$	**Maximum measure temperature** $T_{\max}[{}^{0}C]$
+05	33.66
+10	33.05
+15	32.40
+20	31.40
-20	35.92
-15	35.78
-10	35.30
-05	34.79

*Table.6. the atmospheric temperature and the influence of relative humidity on the surface temperature measurement at zero load after **60 minutes**.*

Relative humidity [%]	**Maximum measure temperature** $T_{\max}[{}^{0}C]$
20%	34.85
30%	35.29
40%	35.66
50%	36.06
75%	37.26
90%	37.67
100%	38.10
Atmospheric temperature $T_{atm}[{}^{0}C]$	**Maximum measure temperature** $T_{\max}[{}^{0}C]$
+05	35.56
+10	35.04
+15	34.48
+20	33,90
-20	37.74
-15	37.36
-10	36.95
-05	36.52

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Table.7. The Atmospheric Temperature And Relative Humidity Influence On Surface Temperature Measurements For Full Load [2.5Nm] After 10 Minutes

Relative humidity [%]	**Maximum measure temperature** $T_{\max}[{}^0C]$
20%	43.16
30%	43.42
40%	43.96
50%	44.24
75%	44.81
90%	45.10
100%	45.40
Atmospheric temperature $T_{atm}[{}^0C]$	**Maximum measure temperature** $T_{\max}[{}^0C]$
+05	43.63
+10	42.99
+15	42.32
+20	41,60
-20	46.30
-15	45.83
-10	45.33
-05	44.80

*Table.8.The Atmospheric Temperature And Relative Humidity Influence On Surface Temperature Measurements For Full Load [**2.5Nm**] After **60 Minutes***

Relative humidity [%]	**Maximum measure temperature** $T_{\max}[{}^0C]$
20%	51.67
30%	52.10
40%	52.96
50%	53.42
75%	54.95
90%	55.28
100%	55.77
Atmospheric temperature $T_{atm}[{}^0C]$	**Maximum measure temperature** $T_{\max}[{}^0C]$
+05	52.90
+10	52.37
+15	51.80
+20	51,20
-20	55.15
-15	54.76
-10	54.34
-05	53.89

6.1. Surface temperature for different emissivity and temperature reflection

The Thermogram of measurement in figure.5 confirms that the emissivity is not a great influence on the measurement if the temperature of reflection is close to ambient temperature. The temperature of reflection will be more influential than the emissivity (for high emissivity), depending on the environment of the measure. This is a statement that is clearly shown in table.9. And in order to get the correct values parameters for this whole operation check table.10.

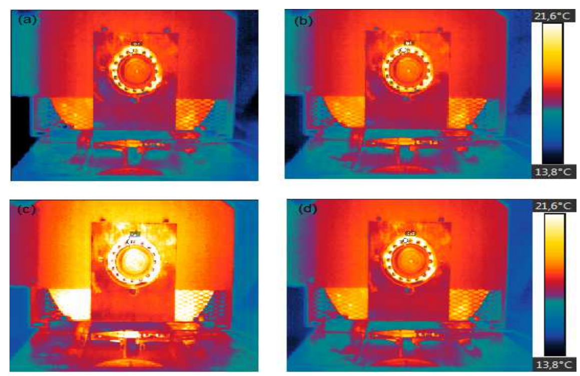

Figure.5. Thermogram Of Measurement With:

(a) : $\varepsilon = 0,90$; $T_{refl} = 20^0C$; $T_{amb} = 20^0C$

(b) : $\varepsilon = 0,98$; $T_{refl} = 20^0C$; $T_{amb} = 20^0C$

(c) : $\varepsilon = 0,90$; $T_{refl} = -15^0C$; $T_{amb} = 20^0C$

(d) : $\varepsilon = 0,98$; $T_{refl} = -15^0C$; $T_{amb} = 20^0C$

Table.9. Surface Temperature Variation For Different Emissivity And Reflection Temperature

Determining the surface temperature area of SP01			
Reflected temperature $T_{refl}[{}^0C]$	ε = 0.9	ε = 0.95	ε = 0.98
-45	27	24,4	22,9
-15	25,3	23,6	22,6
0	24,1	23	22,4
20	22,2	22,1	22

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Table.10. Correct Values Parameters (SP01)

Correct parameters	***Values***	$T_{max}[^0C]$	$T_{min}[^0C]$
Emissivity	0.95	52.40	50.30
Reflected apparent temperature	+20 ^{0}C		
Object distance	1m		
Atmospheric temperature	+20 ^{0}C		
Relative humidity	50%		
Ambient temperature laboratory	20 ^{0}C		

Figure.6. Thermal Image (Thermogram) With Correct Parameters, 60minutes Of Continues Operation With The Braking Torque [2.5Nm] Set In Camera FLIR T440. (See Table.9)

The engine was tested under different conditions. The first test is the measurement of the engine temperature at no load. In *Figure.7* we see how the maximum temperature measured increases every minute for a continuous operation of a total 60 minutes. From the measurements, it is clear that the temperature increases rapidly during the first 30 minutes then with a slower pace for the next few minutes.

In order to find the effects of environmental factors on the infrared temperature measurement, Figure-8 shows how the maximum values are measured for changes in the values of the actual atmospheric temperature. Similarly, we find that incorrect values on an atmospheric temperature have little influence on the measurement results. Figure-9 shows how defective relative humidity affects the thermographic results. Again, the correct moisture content has little influence on the thermographic measurements. Details of how the atmospheric temperature and the relative humidity harm alter the maximum measured temperature of the motor are shown in Tables 5 and 6, respectively.

The same measurements were carried out in the case of full load conditions as well. Tables 7 and 8 show the minor effect of temperature and humidity on the wrong temperature maximum measured. Figure-7 shows the maximum temperature measured for both scenarios (no load and full load). As expected for full load conditions, the measured temperatures are higher.

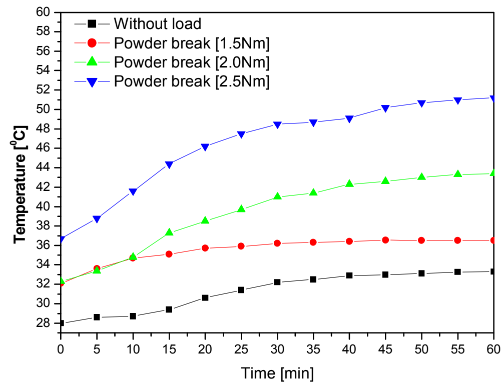

Figure.7. The Maximum Measured Temperature.

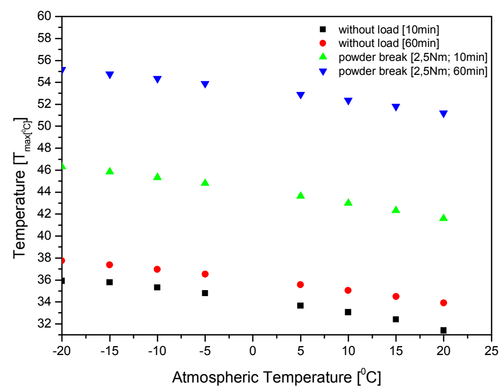

Figure.8. The Atmospheric Temperature Influence On Thermographic Measurements

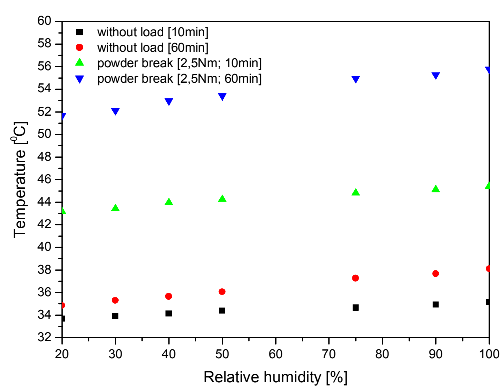

Figure.9. The Relative Humidity Influence On Thermographic Measurements

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7. CONCLUSION

Wide applications in numerous sectors such as electronics, industry and engineering are attained by Thermographic Cameras. Although these cameras are able to measure temperatures very precisely if certain conditions are fulfilled, they are frequently used for rough measurements. This includes, measuring the temperature distribution on an asynchronous motor, when all that has to be found out in the first phase is which places are more thermally loaded and which are less. It is compulsory to know the surface emissivity and the distance from the measured object when the measurements are precise. The development will probably proceed in the direction of increasing the resolution of acquired images. The motor tested under different conditions and the influence of environmental parameters on the accuracy of the measurements was also investigated.

NOMENCLATURE

W_{BB} : Black-body spectral radiant Emittance $[W/m^2]$

W_{GB} : Gray Body Spectral Radiant Emittance $[W/m^2]$

λ : Wavelength $[\mu m]$

T_{refl} : Reflected Ambient Temperature $[^0C]$

T_{atm} : Atmosphere Temperature $[^0C]$

T_{obj} : Temperature Objects $[^0C]$

$T_{\max}$: Maximum Temperature $[^0C]$

$T_{\min}$: Minimum Temperature $[^0C]$

T_{av} : Average Temperature $[^0C]$

ε : Emissivity

σ : Constant Stefan-Boltzmann $5,6697.10^{-8}\ W/m^2k^2$

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