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THE STUDY OF THE THERMAL PROFILE OF A THREE-PHASE MOTOR UNDER DIFFERENT CONDITIONS

J. G. Fantidis, K. Karakoulidis, G. Lazidis, C. Potolias and D. V. Bandekas
Department of Electrical Engineering, Institute for Technological Education, Kavala, Greece
E-Mail: dbandek@teikav.edu.gr

ABSTRACT

Infrared thermography is one of the most cost-effective predictive maintenance technologies which are quickly, accurately available without interrupting the operations and locate problems in various types of systems before any failure. Electrical thermography is the most widely performed application of Infrared thermography. It is used virtually around the world to evaluate the condition of electrical systems and equipment. Thermal imaging can help someone to track the temperature at which any electrical motor is operating, which is crucial to the longevity of the motor. This article deals with the temperature measurements on an induction motor and describes the influence of parameters such as the relative humidity and the environmental temperature on the measured values.

Keywords: electric motor, thermography, temperature measurement, measurement errors.

1. INTRODUCTION

Infrared thermography (IRT) is a non-destructive technique (NDT) for detecting "hot spots", which are temperature-differential and possibly will indicate problems such as loose electrical connections or excessive friction in machinery and mechanical systems. Thermography is a technique of producing a live thermal picture of an object based on the infrared radiation received from it. Classical cameras record and store images by capturing light in the visible range (450-750 nanometer) of the electromagnetic spectrum. A thermographic or infrared camera, is a camera that forms an image capturing light of longer wave-lengths- known as infrared in wavelengths- as long as 14,000 nm (14 μm). All objects with a temperature above absolute zero emit energy (infrared light) proportional to its surface temperature. Thermographic cameras can be generally divided into two categories, with cooled infrared image detectors and with uncooled detectors [1-3].

Thermography can be used for a wide variety of applications such as electrical equipment (electric motors, fuse blocks, control circuits, circuit breakers, loose connections or poor contacts, unbalanced loads, overloading, transformer overheated bushings, blocked /restricted cooling passages etc) [4-5], boilers and steam systems, mechanical equipment [5], building diagnostics [6], process monitoring [7], human and veterinary medicine [8]. Thermography is a powerful maintenance tool. Temperature and the resulting thermal behavior are the most critical factors in the reliability of any operation or facility. Temperature is by far the most measured quantity in any industrial environment. For these reasons, monitoring the thermal operating condition of electrical and electromechanical equipment is considered to be key to increasing operational reliability.

The primary scope of this article is to study the thermal profile of a three-phase motor under different conditions. The effect of environmental factors such as humidity and temperature on qualitative thermography was also investigated. All the measurements performed at the Technological Institute in Kavala on the electric machine laboratory.

2. IR MEASUREMENT - BASIC EQUATIONS

According to the Stefan-oltzmann law, a black body radiates energy E per unit surface in unit time which is analogous to the fourth power of the black body's absolute temperature *T*.

$$E = \sigma \cdot \mathrm{T}^4 \qquad (1)$$

where σ is the Stefan-Boltzmann constant and equals to $5.6704 \cdot 10^{-8}$ (W/m^2K^4). In a general case, a typical object does not absorb or emit the full amount of irradiance. Instead, it radiates a portion of it, characterized by its emissivity ε.

$$E = \varepsilon \cdot \sigma \cdot \mathrm{T}^4 \qquad (2)$$

where E is the radiometric force, (W/m^2). The emissivity of a given body surface is a function of the angle of observation α, wavelength λ, body temperature T, and time t.

The emissivity (ε) of a material is the capability of the material surface to emit heat radiation. It is a measure of a material's ability to radiate absorbed energy. ε in short is a measure of how much radiation is emitted from the object, compared to that from a perfect blackbody (a black body absorbs the total radiation incident on it and hence appears black in color) and is always less than 1. ε is the remaining component of radiation after transmissivity (t) and reflectivity (ρ) are taken into account [9-10].

$$\varepsilon = 1 - (t+\rho) \qquad (3)$$

3. EFFECT OF ENVIRONMENTAL FACTORS

Relative humidity: Relative humidity is the amount of water in the air at any particular temperature relative to the saturation level. According to previous studies, an incorrect value in humidity has negligible effect on object temperature measurement and increases with the object temperature.

Reflected temperature: Reflected temperature can modify the actual temperature of the investigated object. In case the background has more emissivity than the target object, infrared camera will see the background hotter than the target. If the target object has more emissivity than background, then target object will be hotter than background.

Wind speed: Wind speed can cause a great change to the accuracy of temperature measurement whereas in laboratory conditions it has insignificant effects.

Sun heat: Like the wind speed, the sun heat has effective influence on thermographic measurements but in laboratory conditions its effects are not important [11-13].

4. INFRARED CAMERA JENOPTIK VarioCAM® 7800

The Jenoptik thermographic system VarioCAM® 7800 was used for the purposes of this work. It is a high-resolution, portable, digital color infrared and visual camera. An uncooled Focal Plane Array microbolometer is used as an infrared radiation sensor. The thermographic system during the measurement has a standard 30mm lens with minimum focus 0.3m IFOV 0.8 mrad and FOV (30×23)°, and reaches a resolution of 640×480 pixels (with resolution enhancement onto 1280×960 pixels). It communicates with the PC via FireWire (IEEE 1394) which are later processed in the suitable analyzing software IRBIS® 3 professional. Table-1 shows the main specifications of the thermographic system Vario CAM® 7800.

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

Parameter	Value
Spectral range	7.5 □ 14 µm
Temperature measuring range	-40 □ 1200 °C
Temperature resolution at 30°C	Better than 0.08 K
Measurement accuracy	± 1.5 K (0 □ 100 °C), ± 2% (< 0 and >100) °C
Emissivity	Adjustable from 0.1 to 1, in increments of 0.01
Spatial resolution/IFOV	0.8 mrad
Field of view/FOV	30° (H) ×23° (V)

5. TERCO 1007 - 695 INDUCTION MOTOR SLIP RING

Usually any electric motor should be checked when they run under normal operating conditions. Thermography images of electric motors reveal their operating conditions as reflected by their surface temperature, capturing infrared temperature measurements of a motor's temperature profile as a two-dimensional image. An infrared camera can capture temperatures at thousands of points at the same time, for all of the critical components of a motor.

Electric motors are probably the biggest headache for the electrical engineers, since they have lots of breakable parts such as electrical connections and windings, they operate at variable speeds and loads, and they drive many different pieces of equipment [14]. The environment surrounding electric motors alters with respect to dirt, dust and ambient temperature. Infrared thermal pictures are very useful for both troubleshooting motor problems as well as for condition monitoring. In this article a 3-phase slip-ring motor TERCO 1007 - 695 was used. Table-2 provides the specifications of the TERCO 1007 - 695 induction motor.

Table-2. Motor Specifications.

Parameter	Value
Power Supply	3 phase 690/400 V 1.7/3 A 50 Hz
Power	1.1 kW
Speed	1440 rpm
Moment of inertia	J = 0.012 kgm^2
Dimensions	400 mm x 300 mm x 350 mm Shaft height 162 mm
Weight	42 kg

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Table-3. The atmospheric temperature and the relative humidity influence on thermographic measurements for zero load after 7 minutes of continues operation.

Atmospheric temperature	**Maximum measure temperature** (°C)	**Relative humidity**	**Maximum measure temperature** (°C)
+20	48.99	100%	52.76
+15	49.68	90%	52.51
+10	50.33	80%	52.25
+5	50.94	48%	51.53
27.4°C	51.53	40%	51.29
-5	52.07	30%	51.06
-10	52.58	20%	50.84
-15	53.06		
-20	53.51		

Table-4. The atmospheric temperature and the relative humidity influence on thermographic measurements for zero load after 40 minutes of continues operation.

Atmospheric temperature	**Maximum measure temperature** (°C)	**Relative humidity**	**Maximum measure temperature** (°C)
+20	68.22	100%	72.42
+15	68.80	90%	71.99
+10	69.36	80%	71.58
+5	69.88	48%	70.38
27.6°C	70.38	40%	69.98
-5	70.84	30%	69.61
-10	71.27	20%	69.23
-15	71.68		
-20	72.06		

Table-5. The atmospheric temperature and the relative humidity influence on thermographic measurements for full load after 7 minutes of continues operation.

Atmospheric temperature	**Maximum measure temperature (°C)**	**Relative humidity**	**Maximum measure temperature (°C)**
+20	53.76	100%	57.56
+15	54.48	90%	57.26
+10	55.15	80%	56.97
+5	55.79	56%	56.40
26.7°C	56.40	40%	56.12
-5	56.96	30%	55.58
-10	57.49	20%	55.32
-15	57.99		
-20	58.46		

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Table-6. The atmospheric temperature and the relative humidity influence on thermographic measurements for full load after 40 minutes of continues operation.

Atmospheric temperature	**Maximum measure temperature** (°C)	**Relative humidity**	**Maximum measure temperature** (°C)
+20	75.36	100%	79.93
+15	75.96	90%	79.44
+10	76.53	80%	79.11
+5	77.06	53%	77.58
26.8°C	77.58	40%	77.12
-5	78.05	30%	76.26
-10	78.50	20%	75.83
-15	78.92		
-20	79.31		

6. CASE STUDY: MEASUREMENT OF TERCO 1007 - 695 MOTOR THERMAL PROFILE

The motor was tested under different conditions. The first test was the measurement of the temperature of the motor with zero load. Figure-1 shows how the maximum measured temperature increases every minute for a totally 40-minute continuous operation. According to the measurements, it is clear that the temperature increases rapidly during the first 15 minutes and with slower rate for the next minutes.

In order to find the effects of environmental factors on infrared temperature measurement, Figure-2 shows how the maximum measured values changes for temperature values ±20°C of real atmospheric temperature. From the Figure-2 becomes obvious that the wrong values on atmospheric temperature have little influence on the results of the measurements. Figure-3 depicts how the faulty relative humidity affects the thermographic results. Again the incorrect humidity has little influence on the thermographic measurements. Detailed information of how temperature and relative humidity wrongs alter the maximum measured temperatures of the motor are shown in Tables 3 and 4, respectively.

The same measurements are realized in the case of full load condition as well. Both temperature and humidity errors have minor effects on the measurements (Figures 4 and 5). Tables 5 and 6 demonstrate the minor effect of the temperature and humidity wrongs on the maximum measured temperature. Figure-6 illustrates the maximum measured temperature for the two scenarios (without load and full load). As expected for the full load conditions the measured temperatures are higher. The visual and the real thermal images of the motor at the time 0 (before the motor starts) are shown in Figure-7. Figures 8 and 9 exhibit the thermography images after 7 and 40 minutes of continuous operation for zero and full load conditions.

In order to study how the maximum measured temperature changes during the time of operation the Terco 1007 - 695 motor was tested without load and for full load conditions for 200 minutes. Figure-10 illustrates the fluctuation of the maximum measured values. It is apparent form Figure-10 that the temperature on the motor raised steeply during the first 15 minutes. Generally about 40 minutes were required to reach a relevant steady state. Figure-11 shows the original thermal images of machine after 200 minutes of continuous operation. The higher temperatures in the case of full load are clearly evident in Figure-11. The most common fault on a 3 phase AC motor, the loss of one phase was also studied. For safety reasons the engine had 50% of full load and the "fault" occurred after one minute of normal operation (Figure-12).

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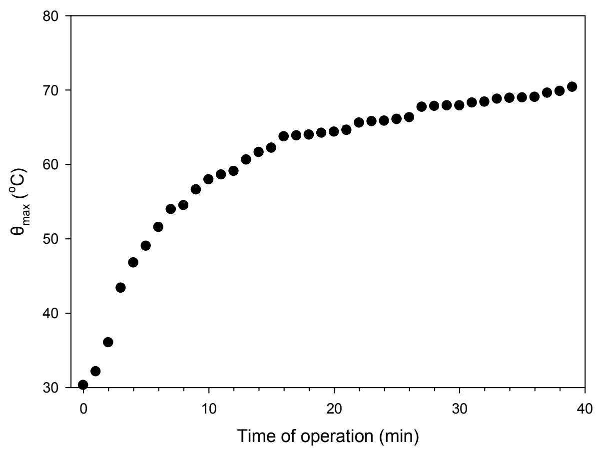

Figure-1. The maximum measured temperature without load.

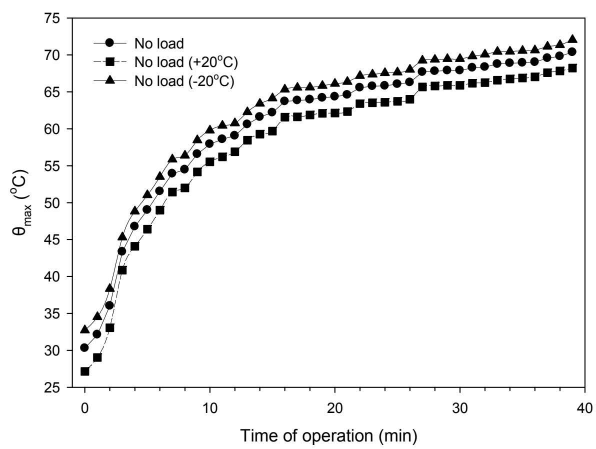

Figure-2. The atmospheric temperature influence on thermographic measurements for zero load.

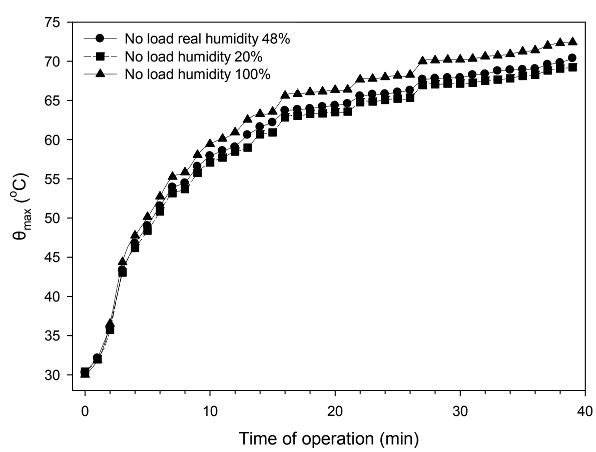

Figure-3. The relative humidity influence on thermographic measurements for zero load.

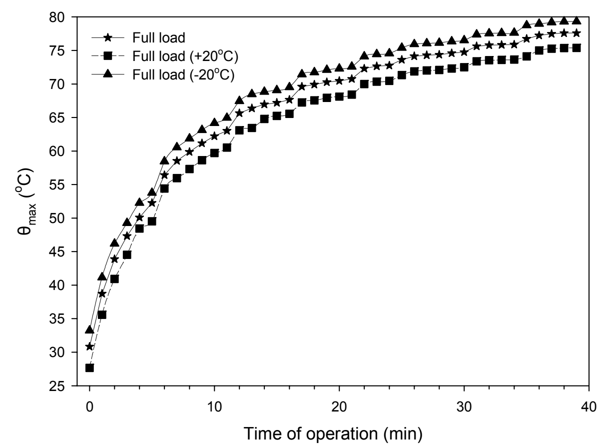

Figure-4. The atmospheric temperature influence on thermographic measurements for full load.

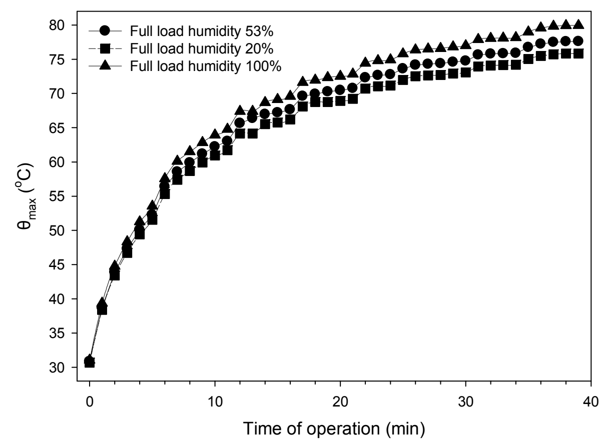

Figure-5. The relative humidity influence on thermographic measurements for full load.

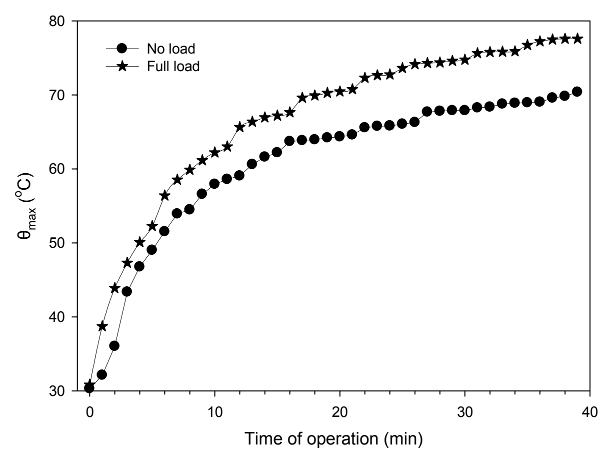

Figure-6. The maximum measured temperature for the two scenarios.

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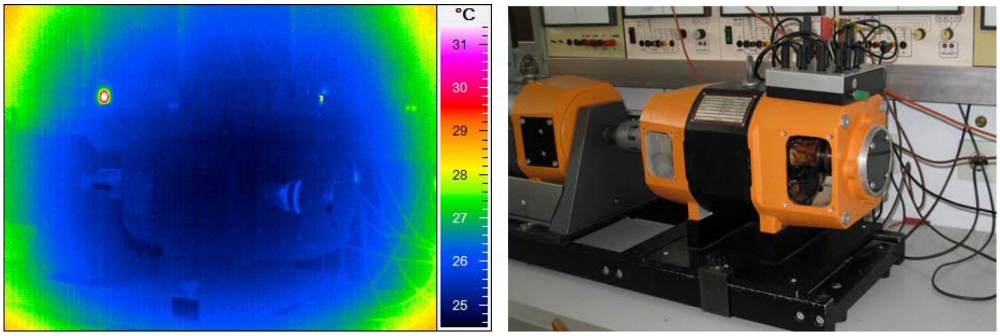
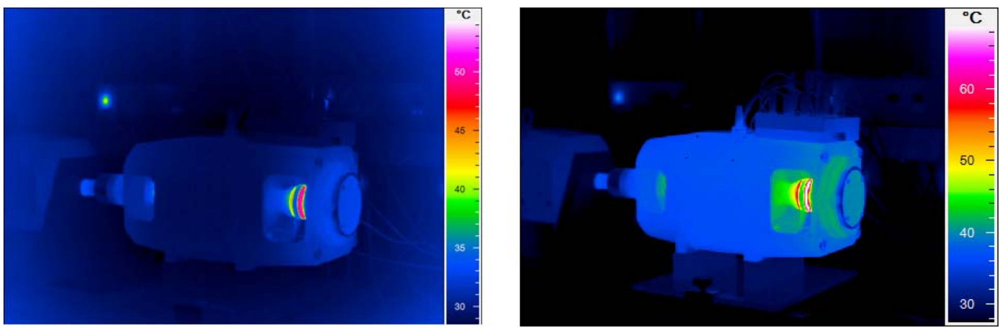


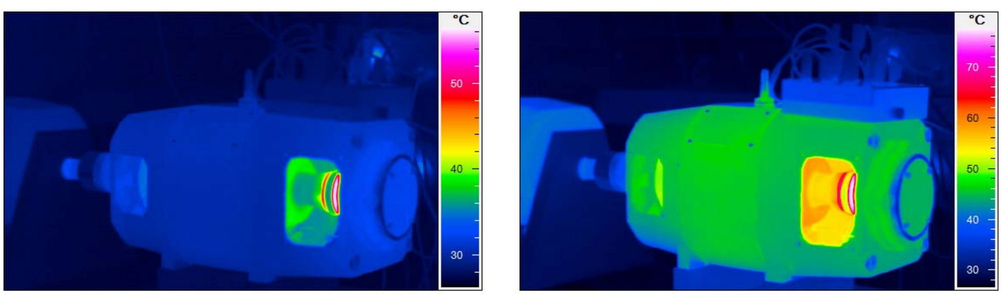
(a) (b)

Figure-7. (a) The real thermal image (before the motor starts) and (b) the visual image of the tested.



(a) (b)

Figure-8. Thermal images after (a) 7 minutes (b) 40 minutes of continue operation without load.



(a) (b)

Figure-9. Thermal images after (a) 7 minutes (b) 40 minutes of continue operation for full load.

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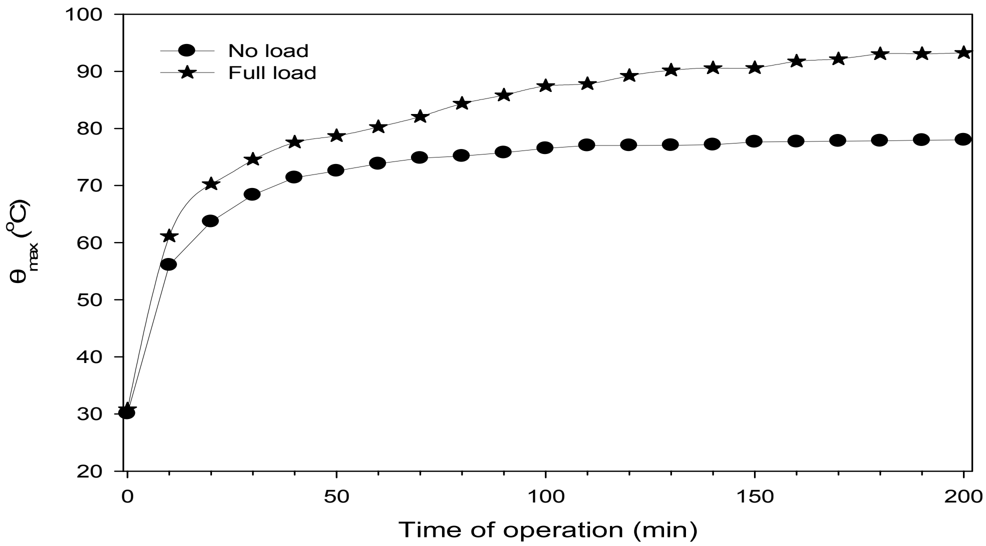

Figure-10. Fluctuations of the maximum measured values for 200 minutes of continue operation.

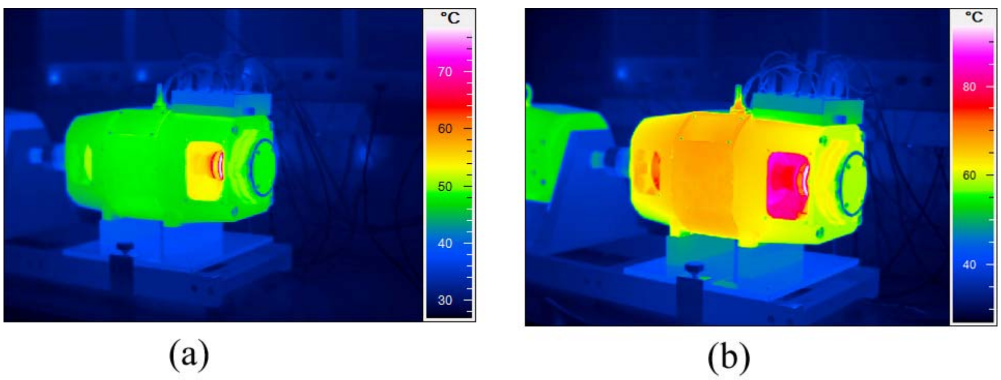

Figure-11. Thermal images after 200 minutes of continue operation (a) foe zero load (b) for full load.

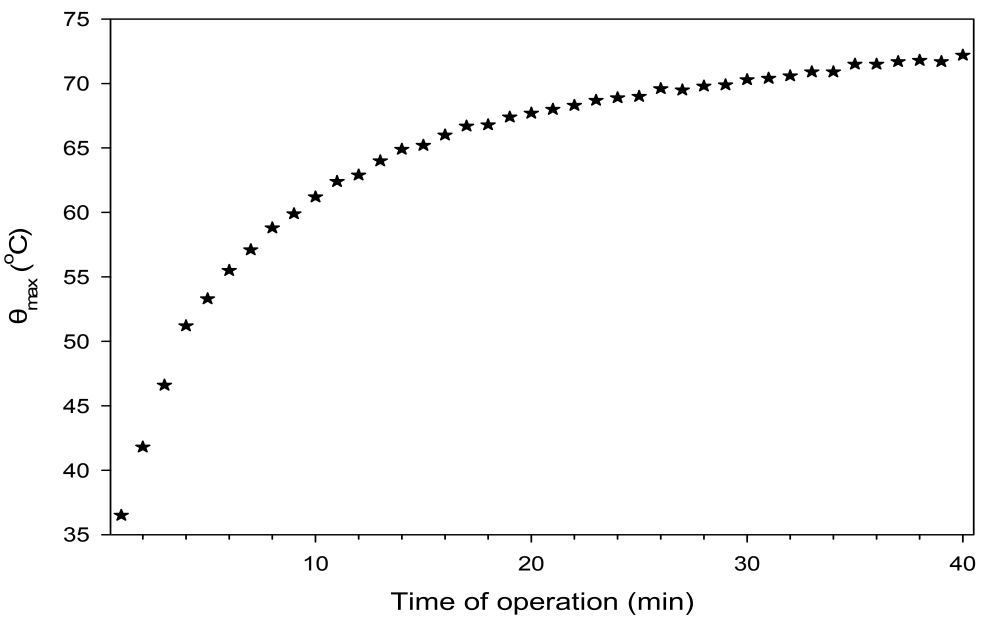

Figure-12. The maximum measured temperature for 50% load after the loss of one phase.

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7. CONCLUSIONS

Infrared thermography is a non-destructive, nonintrusive, noncontact method for inspecting electrical equipment for defective components or connections. The main application for thermography has always been, and still is electrical system inspections. In the present article a portable, high-resolution infrared thermographic system is used in order to accurate measurements of the temperature distribution of the Terco 1007 - 695 induction motor. The motor tested under different conditions and the influence of environmental parameters such as the temperature and relative humidity on the accuracy of the measurements was also investigated.

REFERENCES

[1] R. S. Kad. 2013. IR thermography is a Condition Monitor Technique in industry. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. 2(3): 988-993.

[2] H. Kuchynkova and V. Hajek. 2011. Utilization of Thermal Systems at Power Electrical Engineering. Zeszyty Problemowe - Maszyny Elektryczne. 90(2011): 129-134.

[3] R. A. Sultan, S. W. Guirguis, M. M. Younes and E. E. El-Soaly. 2013. Delamination Detection by Thermography. International Journal of Engineering Research and Applications. 3(1): 279-288.

[4] M. S. Jadin and S. Taib. 2012. Recent progress in diagnosing the reliability of electrical equipment by using infrared thermography. Infrared Physics and Technology. 55(2012): 236-245.

[5] A.MD. Younus and B. Yang. 2012. Intelligent fault diagnosis of rotating machinery using infrared thermal image. Expert Systems with Applications. 39: 2082-2091.

[6] Y. Shi, H. Chen, Q. Xu, D. Li, Z. Wang and X. Fang. 2006. Application of Infrared Thermography in Building Energy Efficiency. Proceedings of the 6th International Conference for Enhanced Building Operations, Shenzhen, China, November 6-9.

[7] F.J. Madruga, D.A. Gonzalez, J.M. Mirapeix and J.M. Lopez-Higuera. 2005. Application of infrared thermography to the fabrication process of nuclear fuel containers. NDT and E International. 38: 397-401.

[8] A.L. Shada, L. T. Dengel, G. R. Petroni, M. E. Smolkin, S. Acton and C. L. Slingluff. 2013. Infrared thermography of cutaneous melanoma metastases. Journal of Surgical Research. 182(1): 9-14.

[9] S. Stipetic, M. Kovacic, Z. Hanic and M. Vrazic. 2012. Measurement of Excitation Winding Temperature on Synchronous Generator in Rotation Using Infrared Thermography. IEEE Transactions on Industrial Electronics. 59(5): 2288-2298.

[10] E. C. Bortoni, R. T. Siniscalchi and J. A. Jardini. 2010. Hydro Generator Efficiency Assessment Using Infrared Thermal Imaging Techniques. Power and Energy Society General Meeting, 25-29 July, Minneapolis, USA. pp. 1-6.

[11] M. Barański and A. Polak. 2011. Thermal diagnostic in electrical machines. Electrical Review. 87: 305-308.

[12] M. Barański and A. Polak. 2010. Thermographic diagnosis of electrical machines. XIX International Conference on Electrical Machines, Rome, Italy.

[13] A.S. N. Huda, S. B. Taib and D. B. Ishakm. 2012. Necessity of Quantitative Based Thermographic Inspection of Electrical Equipments. PIERS Proceedings, Kuala Lumpur, Malaysia, March 27-30.

[14] M. Narrol and W. Stiver. 2005. Quantitative Thermography for Electric Motor Efficiency Diagnosis. Proceedings of the Canadian Design Engineering Network (CDEN) Conference, Kaninaskis, Alberta, July 18-20.