Experimental Study of Heating in Induction Motors for Several Load Conditions

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Abstract: – This paper presents an experimental study of heating of an induction motor under several load conditions with many thermocouples placed in the stator and the bearing endcap .The application has been done for a totally enclosed fan cooled (TEFC) 4 kW, 3 phases, 2 poles, 380V induction motor manufactured in Algeria by "Electro - Industries".

Key-Words : Temperature - Induction motor - Heating

1 Introduction

The highest volume of machines manufactured by "Electro - Industries, Algeria" are the three phase squirrel cage induction machines of totally enclosed fan cooled (TEFC) design. These robust machines are now being designed with material that are highly temperature sensitive, and operated much near to their overload limits because of stringent high torque to inertia requirements. Therefore, thermal failure of the machine can occur either by thermal breakdown of the stator winding insulation or by mechanical distortion and fatigue of the rotor structure. Because of these and other constraints, there is an important need for accurate on line estimation and measurement of temperature particularly in those hot spots where a risk of adverse thermal conditions increases. Thus ensuring that the temperatures remain within their designed limits [1], [2].

The determination of temperatures in induction machines can follow two possible approaches : a preferred technique involving an estimation of temperature through the use of thermal models [3],[4] [5] [6] , [7]. This approach can track both steady state [4] and transient temperature changes [5] or to determine the losses under different conditions [6], [7], [8]. However, the accuracy achieved is not very good and the temperature information is lost when the drive is reset. That is why in addition to the use of thermal models the experimental study of the heating is necessary to determine the temperatures and also the losses and to compare the machine's behaviour under different load and /or different supply conditions .

In this paper, an experimental study is carried out to measure the temperatures in different parts of the machine via a number of thermocouple embedded in strategic points. The results obtained using sinusoidal voltage supply under several load conditions are presented. The results can be generalised for a wide range of machines sizes with similar thermal insulation.

2 Description of experimental work

The test rig consists of a standard 3 phases, 4 kW, 380V, TEFC squirrel cage induction motor coupled to a magnetic brake. Details of the motor design are presented in Table 1 .

Rated output power	4 kW
Rated line voltage	380 V
Rated line current	8.1 A
Stator winding connection	$\triangle$
Stator slots	24
Rotor slots	20
Insulation class	F
Rated speed	2895 rpm
Number of poles	2

Table 1

The temperature measurements at different points within the test motor were obtained using six sensors (thermocouples) placed at strategic points of the motor. Figure 1 shows the location of these sensors. The stator slot winding sensor was inserted between the array of winding conductors and the slot liner, and the stator iron thermocouples were placed into very small drilled holes. The end winding sensor was located to the radial centre of end windings.

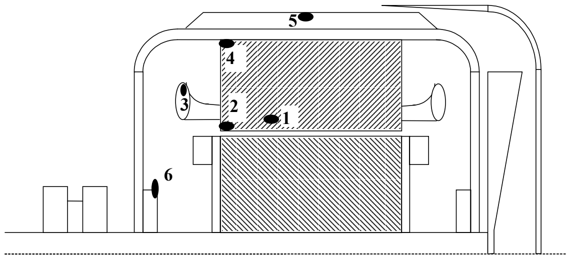

Fig. 1 Axial view of the motor showing the locations of the sensors.

(**1**) : Slot winding , (**2**): Stator Teeth, (**3**): End winding

(**4**) : Stator iron, (**5**) : Frame, (**6**) : Bearing endcap

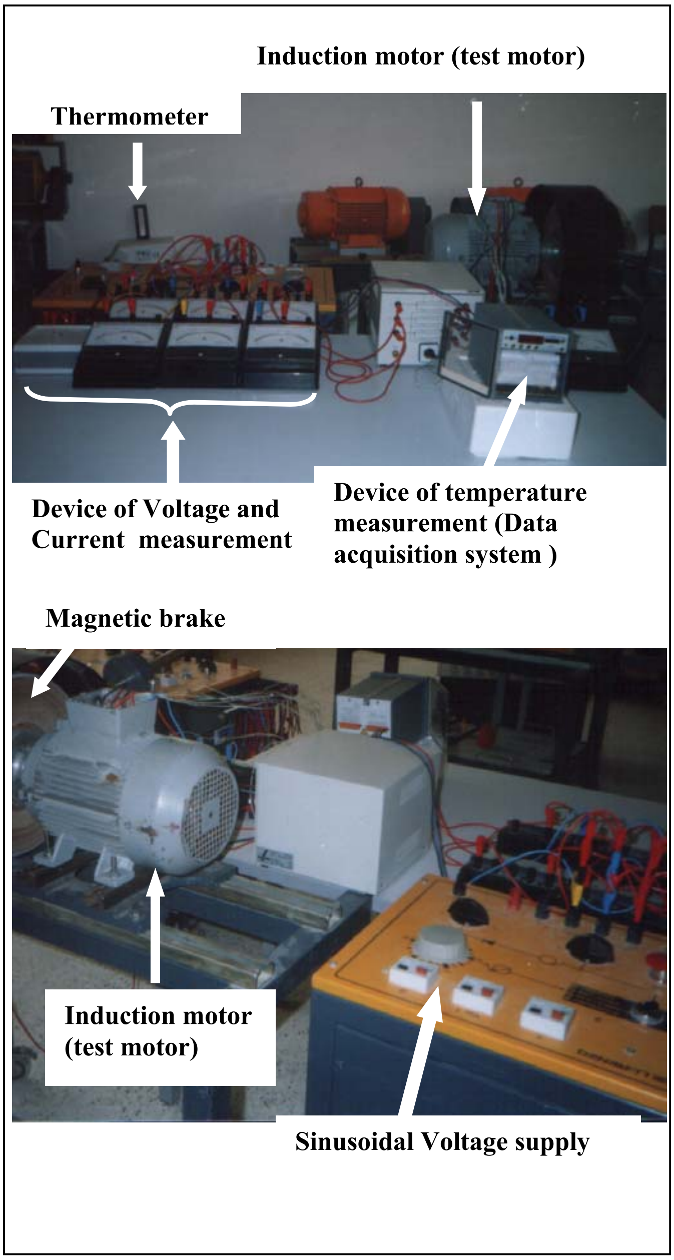

Fig.2 Test rig

3 Results and discussion

The results presented were obtained for the above described test layout and shown in Figure 2 . The heating and cooling curves corresponding to each point were obtained using a sinusoidal supply and several load conditions. First, two no load tests were carried out , the first with the fan on and the second with the fan taken away. The results are shown in Figure 3 and Figure 4 respectively.

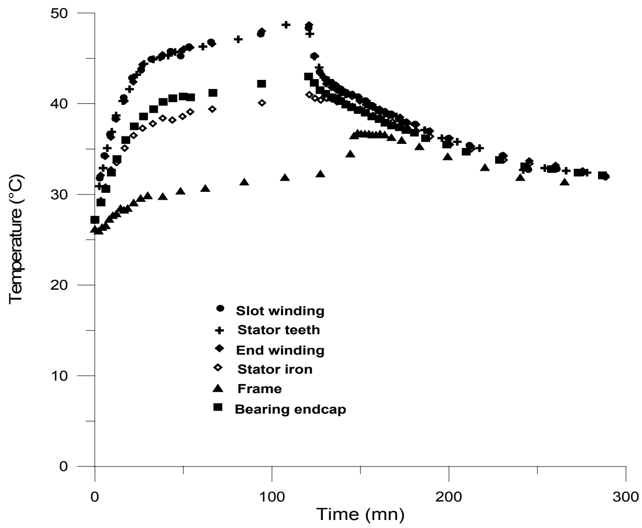

Fig.3 Heating and cooling curves at no-load with ventilation

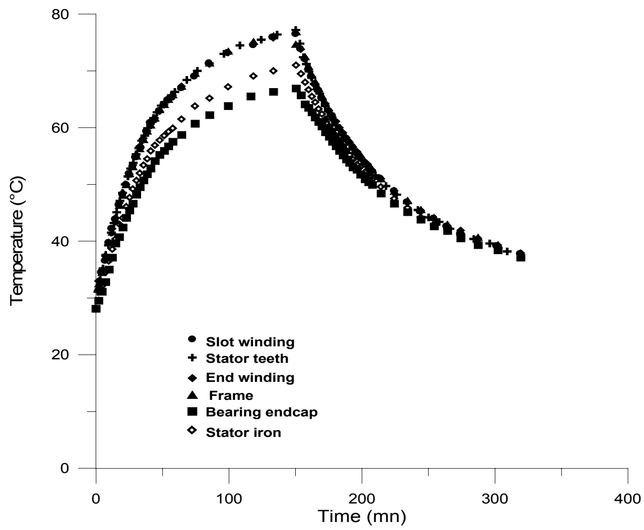

Fig.4 Heating and cooling curves at no-load without ventilation

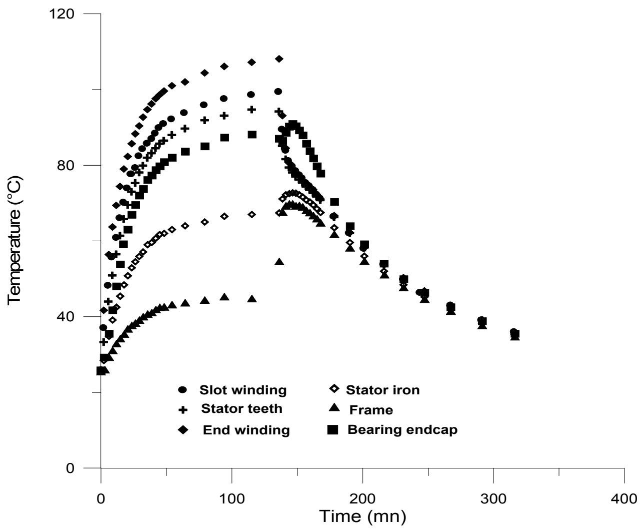

Fig.5 Heating and cooling curves at full-load with ventilation

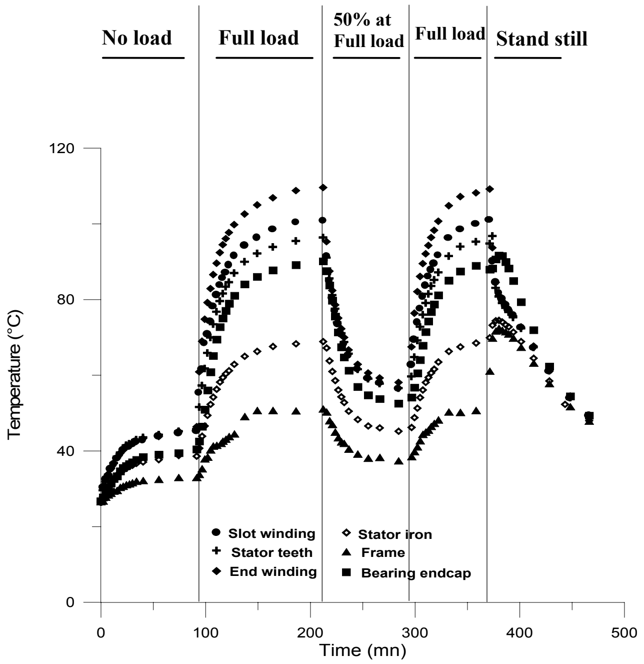

Fig.6 Heating curves for several load conditions with ventilation

With the fan on (Figure 3) the thermal steady state is reached in 80 minutes and the hottest temperature was found to be at the end windings away from the fan reaching 50°C. The difference in temperature between the hottest point (end winding away from the fan) and the least hot point (stator iron) is found to be 8°C. As expected and as the thermal equilibrium is attained the cooling curves start closing up together to reach the steady state temperature.

In condition without ventilation (Figure 4), the steady state was not completely reached despite the long time elapsed (150 mn). The hottest point is always found to occur at the non-ventilated side of the end windings reaching 77°C. Whereas, the least hot point was in the bearing whose temperature is 9.7°C less than that of the hottest point.

By comparing the two no load tests with and without ventilation, we noticed that the steady state is reached quicker with than without ventilation. The presence of the fan facilitates the transfer of heat from the hottest point to the least hot and finally to the surroundings.

Figure 5 and Figure 6 show the heating and cooling curves with ventilation but at full load and then at different loads. These curves show that the temperatures become much higher at full load than that at no load showing the importance of losses dissipated at each active part of the machine. Unexpectedly, the hottest temperature occurs always at the non ventilated side of the end winding rather than in the embedded conductors of the slot winding which have higher losses. This is may be due to the importance of cooling that is, the presence of the fan. This question in under investigation by adding another thermocouple at the other side of the machine near the fan.

From Figure 6, it is noticed that the same regular variation of the load does not produce automatically the same temperature difference. Nevertheless, the heat distribution pattern within the motor is identical for different load conditions but with ascending temperature values while increasing the load.
This show that the relationship between the heating and losses is not linear and thus increasing the complexity of heat transfer problem in electrical machines. This problem is further aggravated by the uniformity of cooling using a fan.

4 Conclusion

The experimental investigation carried out permitted to show the distribution of temperatures in the different parts of the test motor. It is shown that the copper losses represent the most influential factor on heating in electrical machines. Moreover, the hottest point is found to be in the non ventilated side of the end winding highlighting the importance of the fan, thus of the cooling.

Thermal modelling of induction motors remains always a complex problem facing electrical machine designers due to the existing nonlinearities between the losses and the different types of cooling leading to a very complicated heat transfer phenomena. Therefore, the results obtained in this experimental study are of particular interest as they can constitute a basis from which more sophisticated and accurate thermal models can be developed. This constitutes a scope of future work in our laboratory.

References

[1] A. Bousbaine , W.F. Low, and M. McCormick, ‘‘Novel Approach to Measurement of Iron and Stray Load Losses in Induction Motors’’, *In Proc. IEE, Vol. 143, N°1, September 1996, pp.78-86.*

[2] J. M. Kauffman, and B.Laporte,‘‘Analyse des Performances des Machines électriques’’, *RGE, N°8, 1994, pp. 36- 40.*

[3] G. Kylander,“ Thermal Modelling of Small Cage Induction Motors ” , *Int. Symp. On Eelct. Power Engin., 1995, pp. 235-240 .*

[4] I.J. Perez and J.K. Kassakian “ A Stationary Thermal Model for Smooth Air-gap rotating Electrical Machines ”, *Elecrt. Machi. Electromech., 1979, 3, pp. 285 - 303.*

[5] P.H. Mellor, D. Roberts, and D.R Turner, “ Lumped Parameters Model for Electrical Machines of TEFC Design” , *In Proc. IEE, Vol. 138, N°5, September 1991, pp.205-218 .*

[6] E.Oliver , R.Perret, and J.Perrard, “ Localisation of the Losses in Induction machines fed from inverters”, *Electrical machines and power systems, Vol. 9, 1984, pp. 401-412.*

[7] M. Benhaddad , K. Yazid and R. Khaldi, ‘‘Vector Control Induction Machine using Rotor Circuit Time Constant ’’, *Int. Symp . on Methods and Models in Automation and Robotics, pp.1-5, 1996.*

[8] A. Bousbaine , W . F. Low , M. McCormick , N. Benamrouche , ‘‘ Thermal Modelling of Induction Motor Based on Accurate Loss Density Measurement ’’, *Proceeding ICEM, Manchester (U.K), September 1992, pp. 953-957.*