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An Experimental Investigation of Heating in Induction Motors

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***Abstract*—**The ability to predict an accurate temperature distribution requires the knowledge of the losses, the thermal characteristics of the materials, and the cooling conditions, all of which are very difficult to quantify. In this paper, the impact of the effects of iron and copper losses are investigated separately and their effects on the heating in various points of the stator of an induction motor, is highlighted by using two simple tests. In addition, the effect of a defect, such as an open circuit in a phase of the stator, on the heating is also obtained by a no-load test.

The squirrel cage induction motor is rated at 2.2 kW; 380 V; 5.2 A; Δ connected; 50 Hz; 1420 rpm and the class of insulation F, has been thermally tested under several load conditions. Several thermocouples were placed in strategic points of the stator.

***Keywords*—**induction motor, temperature, heating, losses

I. Introduction

THE highest volumes of AC machines manufactured by "Electro-Industries, Algéria" are of the three-phase squirrel cage induction machines of a totally enclosed fan-cooled (TEFC) design. These robust machines are now being designed with materials that are highly temperature sensitive, and operated much near to their overload limits because of stringent high torque to inertia requirements. Then, thermal failure of machines 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 online estimation of temperature particularly in those hot spots where a risk of adverse thermal conditions increases. Thus, insuring the temperatures to remain within their designed limits [1], [2] and [3]. The determination of temperature in induction machines can follow two possible approaches. A favoured technique involves an indirect estimation of temperature through the use of thermal modelling [4], [5] and [6]. This approach can track both transient and steady state temperature changes. The second approach involves an experimental investigation which allows the measurement of temperature under different load and supply conditions [7], [8], [9] and [10]. In this paper, we have chosen to carry out an experimental investigation to measure the temperatures in different parts of the machine which was instrumented by a large number of thermocouples. The results are obtained using sinusoidal voltage supply under several loads conditions. The results can be generalised for a wide range of machine sizes with similar thermal insulation.

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II. Experimental Procedure

The basic test rig comprises a 3 phase, 2.2 kW, 380 V, TEFC squirrel cage induction motor, mechanically coupled to a separately excited DC machine. A 50 Hz sinusoidal variable voltage was used to feed the test motor. The test rig used is shown in Fig. 1.

Fig. 1 Test rig

Several tests were carried out on the studied machine. The temperature measurements at different points within the test motor were obtained using eight sensors (thermocouples) placed at strategic points of the motor. The machine was loaded until thermal equilibrium was reached, and then temperature, torque, current, voltage, electrical power, and speed were measured. The iron loss test and the test in D.C. current were made at standstill.

A. Location of sensors

The stator slot winding sensors were inserted into convenient places between the array of windings and the slot liner, and the stator iron thermocouples were inserted into very small drilled holes. The end winding sensors were located to the radial centre of the end winding.

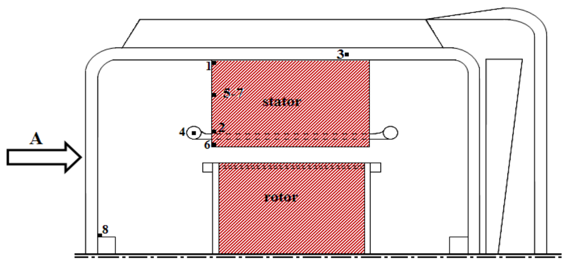

Fig. 2 Location of sensors

1: iron-frame, 2: Stator teeth, 3: Frame, 4: End winding, 5 and 7: Stator iron, 6: Slot winding, 8: Bearing end cap.

B. Results and discussions

The heating and cooling curves corresponding to each point were obtained with sinusoidal supply and under several load conditions.

Fig. 3 represents the heating and the cooling curves of the motor for a variable load (Full load - 50% of load-full load - standstill).

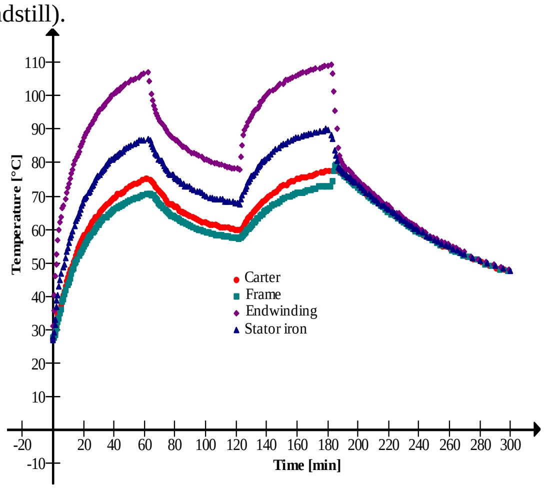

Fig. 3 Heating curves for several load conditions

It is noticed that the temperature in the motor is highest in the end-winding then in the magnetic circuit and finally in the frame. It should be noticed that the time-constant of heating after 120 minutes of operation, is weaker than that corresponding to the beginning of the test. In order, to determine the effect of heating, in the case of an unbalanced mode, two no-load tests were carried out. The first, with three phases and the second with a missing phase. The results of the heating curves are presented in Fig. 4 and 5.

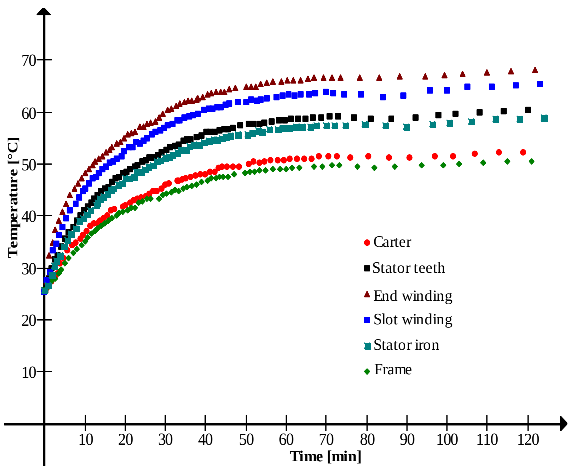

Fig. 4 Heating curves at no load with ventilation

An open circuit in a phase inevitably produces an imbalance of the currents, which, consequently, causes a redistribution of the rises in the temperatures in the various elements of the stator. This defect causes a notable increase in the temperature, in particular, in the stator windings. During this test the power input is more important. Consequently, the increase in losses results in an increase in heating.

To see the impact of iron losses and copper losses, each acting, separately on the motor heating, two tests were carried out in addition to that at no load without ventilation. The first is the iron test which consists of rolling up a certain number of turns around the stator, such that to have only the iron losses. These turns are fed by single-phase alternating voltage source. The second test represents the copper losses in the stator windings. It consists of connecting the three phases in series, and which will be fed by D.C. current. The results of these three tests are represented by the following heating curves Fig. 6.

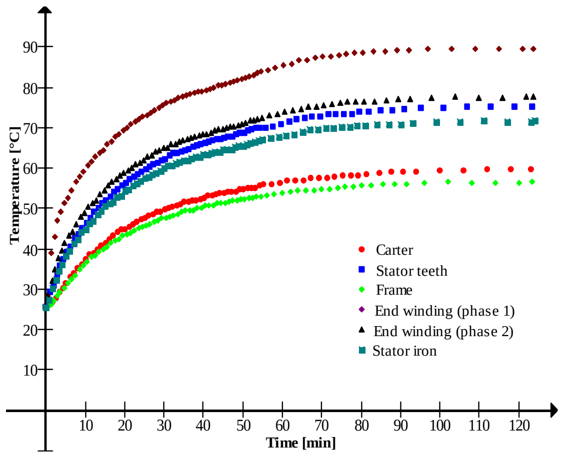

Fig. 5 Heating curves at no load with ventilation and missing phase

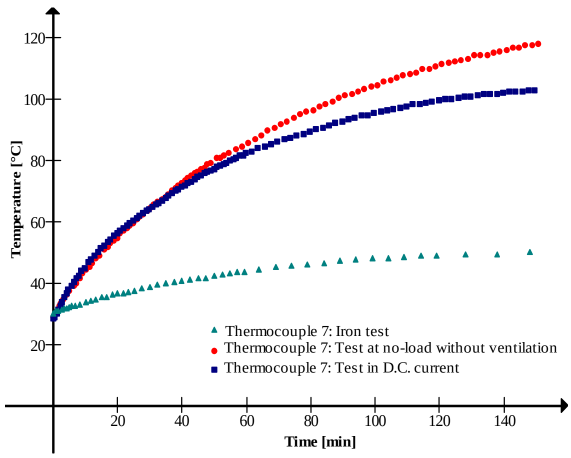

Fig. 6 Heating curves in different test: at no-load, test iron and in D.C. current

During the iron test all the sensors indicate almost identical temperatures (as indicated by sensor 7), as if, the stator is a homogeneous block. Whereas, the two other tests give different temperatures.

The mechanical losses can be neglected in front of copper losses and iron losses. This is can be verified by running the motor using another mover, the D.C machine for example. During this test the thermocouple placed on the bearing produced only 2° C increase in temperature. Thus, the power absorbed during the no-load test can be approximated as the sum of the copper losses and the iron losses.

Fig. 6 shows that the heating in steady state operation, produced by the copper losses and the iron losses during the no-load test without ventilation is the sum of the heating produced by these losses each acting separately. Indeed, after 150 minutes, the heating produced on the level of the iron, indicated by sensor 7 during the no-load test without ventilation, is 88.6 °C compared to that produced by the test in D.C. current test and that by iron test which are respectively 73.2 °C and 17.1 °C. It is deduced that the total heating in the stator iron, is divided into four fifth by the copper losses and a fifth by the iron losses. A difference of about 53.5 °C is noted on all the points considered between the no-load test with ventilation and without ventilation. The heating at no-load test, with ventilation, given by thermocouple 7 is 33.1 °C which leads to the conclusion that ventilation causes a drop in the heating of 37%. If we consider the heating in the three precedent tests with the presence of ventilation, these are as follows: 33.1°C at no-load test, 27.1 °C at DC current test and 6.3 °C in the iron test. Therefore one can conclude that three quarter of the heating of iron comes mainly from the heating of the stator winding.

III. Conclusion

In this paper we presented several heating curves in different locations in the stator of a squirrel cage induction motor, determined experimentally and under different load conditions. It was shown that a defect in the motor, such as an open circuit in a phase, can influence the temperature distribution notably. Three simple tests enabled us to see the influence of the iron losses and the copper losses on the heating of the motor each acting separately. The produced heating, by these two heat sources, is the sum of the heating produced by these two sources each taken separately. The heating of the iron is increased, almost 5 times, with the presence of both copper and the iron losses. The stator behaves like a homogeneous block in the presence of the iron losses alone. It is not the case with the copper losses alone where the temperatures are distributed.

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