MEASUREMENT OF SMALL INDUCTION MOTORS EFFICIENCY USING THERMAL CALORIMETRY

Azzeddine Ferrah, Jehad M. Al-Khalaf Bani Younis, Mounir Bouzguend and Abdelkader Tami
Sohar University, PO BOX: 44, PC: 311, Sohar, Sultanate of Oman
E-mail: a.ferrah@soharuni.edu.om

ABSTRACT

Induction motors are commonly used in industrial applications. The present work represents the design of a high accuracy system for the measurement of small induction motor losses and efficiency. During all tests, ambient temperature, humidity, motor speed and motor frame temperature were recorded manually using digital instruments. The calorimeter temperatures and motor losses were recorded automatically using a high accuracy 12-bit data acquisition system. The calorimeter built is capable of measuring heat losses of up to 1 kW with an overall accuracy better than 3%. The preliminary results obtained demonstrate the suitability of the designed calorimeter for the accurate measurement of losses in small induction motors.

Keywords: induction motor; fractional motor; calorimeter; calorimetry; motor losses; efficiency.

INTRODUCTION

The bulk of electricity consumption in the industrial and commercial sectors is by electric motors. Activities and processes in the industry depend heavily on electric motors including for compacting, cutting, grinding, mixing, fans, pumps, materials conveying, air compressors and refrigeration. Motors are also used widely in the commercial sector for air conditioning, ventilation, refrigeration, water pumping, lifts and escalators. In most industrial countries, the induction motor is the workhorse in most residential, commercial, industrial, and utility applications. Induction motors have high efficiency and a high overload capability. Therefore, they are cheaper and more rugged. They are considered the perfect electrical to mechanical energy converters. In recent years, motor manufacturers are in competition to produce motors with improved efficiency because of the high cost of energy [1]. Most offer energy efficient or high efficient motors as their standard products. However, mechanical energy is more than often required at variable speeds. An induction motor supplied by an adjustable-speed drive can operate over a wide range of frequencies, typically from 0 to 50Hz. This range of frequencies yields rotor speeds from 0 rpm to the rated value. Adjustable-speed AC drives bring about additional losses and hot spot temperatures [2]. These additional losses are very difficult to be measured accurately using conventional wattmeters especially when the machine is loaded. Based on the principle of the calorimetric method suggested by the IEC [3, 4], electric machine losses can be evaluated directly by measuring the dissipated heat within the machine.

An early work on the application of the calorimetric method was presented by Turner et al [5] for the measurement of losses in a 5.5 kW squirrel cage induction motor. This calorimeter was of open type where air was employed as the cooling medium to take away the dissipated heat Turner’s approach demands critical control of the air properties (flow rate, inlet temperature, specific heat, etc). For instance, an air conditioning system has been used to maintain the inlet air at 20 °C. Precautions have also been considered to correct the measurements according to the possible changes due to the air specific heat and density affected by variations of the barometric pressure and relative humidity.

In order to simplify and generalise the induction motor calorimetric loss measurement, an open type calorimeter is designed and constructed in the present work.

LOSSES AND EFFICIENCY IN INDUCTION MOTORS

Efficiency is one of the most important elements that are mentioned when considering the performance of a motor. Motor efficiency is a measure of the effectiveness whereby a motor converts electrical energy to mechanical energy. When motors convert electrical energy into mechanical work some energy is inevitably lost during the conversion. Thus, efficiency for any motor can be determined by its losses. Motor losses fall into two categories; no load losses,
which are fixed and remain constant, and load losses which increase with motor load. Losses in induction motors consist of the four components: iron, friction and windage, stator copper and rotor copper losses. These losses are rather significant and should not be ignored, because they have a direct impact on the efficiency. Breakdown of the motor losses is shown in Figure 1.

![Figure 1 Breakdown of total losses](image)

Efficiency is defined as the ratio of power output to power input. In terms of electrical power, motor efficiencies:

\[
\eta = \frac{\text{Output Power}}{\text{Input Power}} = \frac{\text{Output}}{\text{Output} + \text{Losses}}
\]  

(1)

Determination of efficiencies is based on measurements of input and output power. Efficiency is calculated as the ratio of the measured power to the corrected input power. From [6], efficiency is predominantly low when thermal energy is being changed into mechanical energy.

There is no single efficiency testing method that is held as the standard. There are testing methodologies from three major standard institutes that are widely used throughout the industry. These methods are:

1. IEEE 112 method B
2. IEC 34-2
3. JEC-37

There are some differences among these three methods, but the main difference is in the determination of stray load losses. IEEE 112 method B determines the stray load losses through an indirect process. The IEC standard assumes stray load losses to be fixed at 0.5 % of input, while JEC standard assumes there are no stray load losses. Therefore, the efficiency of a motor when tested under the different standards can vary by several percentage points. It is widely accepted that, among the three, IEEE 112 method B currently gives the most accurate efficiency values. However, the recently developed calorimetric methods have proved to be the ‘Golden Standard’ for efficiency measurement that could yield the highest accuracy ever.

**A NEW CALORIMETRY METHOD**

The designed calorimeter is used to measure directly the loss in a small induction motor operating under various load conditions. The objective is to measure directly the power loss by the motor under working condition. This is achieved by placing the motor inside a 500 mm x 500mm x 500 mm enclosed and fully insulated chamber as shown in Figure 2. To maintain a constant temperature in the chamber a cooling system is arranged to remove heat from the chamber. In steady-state, the power lost, \( P_{\text{loss}} \), in a device is balanced exactly by the heat removed by the coolant. The heat removed is evaluated by taking measurements of the mass flow per second of coolant, the temperature of the coolant at entry to the calorimeter and its temperature at exit from the calorimeter. In steady state then:

\[
P_{\text{loss}} = \dot{m} C_p (T_{\text{out}} - T_{\text{in}})
\]  

(2)

where: \( \dot{m} = \) mass flow rate (kg/s), \( C_p = \) specific heat (J/kg °C), and, \( T_{\text{out}} - T_{\text{in}} = \) temperature rise (°C).

The choice of coolant dictates the type of calorimeter to be designed. After careful consideration air was chosen as coolant for the new design [7].

The designed calorimeter is capable of performing both motor and calibration tests at the same time. This results in a significant simplicity of the calorimeter operation, accompanied instrumentation and measurement system. The duration of each calorimetric test is about 3 hours. The designed calorimeter is found to be economical since the walls and insulation materials are relatively cheap. Also, there is no need for an air conditioning system to maintain the inlet air at a constant temperature while performing calorimetric tests. Therefore, this type of calorimeter is simpler and cheaper and more convenient for induction motor losses measurements with a high order of accuracy.

**Calorimeter Calibration**

In order to test the operation of the constructed calorimeter, a series of calibration tests were performed. The results of the tests are used to determine air temperature rise inside and across each chamber, heater input power and the accuracy of the calorimeter. These quantities are considered as the most important aspects which should be known before starting the calorimeter tests on the induction motor.
The tests were performed at constant airflow rate and various input power levels ranging from 10 W to 250 W. Three DC standard laboratory power supplies were connected in series to achieve the required voltage at the required current. Voltages and currents were measured within ±0.8% and ±1% accuracy, respectively. Based on the experimental results it was found that an airflow rate in the range 2 m³/min is required through the calorimeter for loss measurements of 250 W. This value ensures sufficient air convection around the test induction motor to prevent it from overheating. The average air temperature rise across each chamber was determined to be 24°C for 250W losses.

Experimental results also proved that an average heat loss of 50 W dissipated in each chamber can cause an air temperature rise of 5 °C across that chamber.

The loading system, shown in Figure 4, consists of a steel disk of 140 mm diameter and a thickness of 7 mm. Two steel round masses of 400 g each are diagonally bolted to the disk. For light loading the two mains are replaced by another two of 250 g each. The disk and the mass are firmly fitted to an external shaft that is directly connected to the motor.

The results were conducted with input power in the range 10-250W resulting in a temperature difference of about 1-24 °C between the inside and outside of the Device Under Test (DUT) chamber and of about 24-45 °C between the inside and outside of the Reference (REF) chamber. During each test, the following parameters were measured and recorded:

- Ambient temperature (°C) and relative humidity (%)

<table>
<thead>
<tr>
<th>Load levels</th>
<th>Losses(W)</th>
<th>Ambient Temperature(°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High load</td>
<td>343</td>
<td>26</td>
</tr>
<tr>
<td>Light load</td>
<td>326</td>
<td>27</td>
</tr>
<tr>
<td>No load</td>
<td>225</td>
<td>27</td>
</tr>
</tbody>
</table>

The motor to be tested is placed inside the DUT chamber, with the shaft protruding through the chamber’s wall. The shaft is mechanically connected to the loading system. Thus, allowing the load to be applied to the motor.

The tests were conducted with input power in the range 10-250W resulting in a temperature difference of about 1-24 °C between the inside and outside of the Device Under Test (DUT) chamber and of about 24-45 °C between the inside and outside of the Reference (REF) chamber. During each test, the following parameters were measured and recorded:

- Ambient temperature (°C) and relative humidity (%)
motor’s shaft through a rubber coupling. For the no-load condition the motor is fully disconnected from the loading system. The motor was tested inside the DUT chamber, at different load levels. Figure 5 shows a typical variation of losses within the DUT chamber. The results obtained or different load levels are summarized in Table 1. It was established that fractional induction motors are highly inefficient, since most energy consumed is converted into losses (heat).

To conclude it can be said that the calorimetric method of measuring total losses of induction motor proved to be a valid alternative to the conventional input-output method of heat loss measurement. This alternative method does not required very complicated processes, or expensive equipment. This is a very useful method, which can help motor designers to improve motor efficiency [8].

CONCLUSION

The application of the calorimetric method for the measurement of small induction motor losses has been described in this paper. A tower double chamber calorimeter has been designed and constructed to measure losses of a ½ hp three-phase induction motor. The merits of this approach have been highlighted. The designed calorimeter is capable of measuring losses of other small devices up to nearly 1 kW, including harmonic losses, by simply extending the temperature sensors range. The loading mechanism has also been designed and constructed with the emphasis being placed on how to extend the shaft to the outside of the calorimeter without having air leakage. Experimental tests have been performed to evaluate the heat leakage through the calorimeter walls, edges and corners. The calorimeter accuracy was also experimentally evaluated as better than 3%. It has been experimentally established that small three-phase induction motors produce high losses, resulting in poor efficiency that in some tests reached less than 30%. It was also noticed, during testing, that the relationship between load and losses is not coherent in small induction motors as it is in larger motors. This is a very important point that is worth further investigation. Also the component of heat leakage along the shaft was considered small, considering the small size of the shaft itself. Finally, it has to be pointed out that the results presented here should be looked at as qualitative rather than quantitative results. To make the study more reliable and conclusive, tests should be carried out on several motors of different sizes and from different manufacturers. Objective comparison with other methods should also be presented.

REFERENCES