Electric motor thermal management system using L-shaped flat heat pipes

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Abstract

Heat generation in an electric motor will increase its temperature. The excessive working temperature will reduce the motor performance and shorten its lifetime, therefore, a thermal management system is needed to reduce the working temperature. The objective of this study is to determine the performance of the electric motor thermal management system using L-shaped flat heat pipes experimentally. Evaporator sections of heat pipes are typically placed inside the motor housing or buried in the motor shaft while the condenser sections are placed outside the motor housing and cooled with circulated liquid or air stream. However, in this study, the heat pipes were placed on the surface of the motor housing thus simplifying installation and maintenance. A prototype was made of a 0.5 HP conventional electric motor where the rotor and the coil were replaced by a cartridge heater to simulate the heat generation and to simplify the heat generation adjustment. Eight pieces of L-shaped flat heat pipes were mounted on this prototype. Each evaporator section was mounted on a heat pipe holder that was inserted between the motor fins. Each condenser section was placed in front of the motor fan. Heat sinks were mounted on each condenser section to increase the rate of heat transfer to the ambient air. The heat pipes were made of flattened copper tubes with sintered copper capillary wick and water as working fluid with a filling ratio of 50%. Experiments were conducted with varied heating power while the fan speed was kept constant. The thermal resistance of the motor fins - heat pipe - heat sink did not change much with the heat load. It reached a minimum value of 0.28 °C/W at the heat load of 150 W. The motor surface temperature was reduced from 102.2 °C to 68.4 °C or a reduction by 33.8 °C.

Introduction

Heat generation that occurs in the process of energy conversion in an electric motor will increase its temperature. The excessive working temperature will reduce the motor performance and shorten its lifetime. A thermal management system is needed to reduce the working temperature of the electric motor.

The heat generation inside electric motor consists of Joule losses, iron losses, mechanical losses, and stray load losses [1]. Joule losses associated with the conversion of electric energy into thermal energy that occurs in an electrical conducting material such as copper winding of the stator. Joule losses can be expressed by I^2R, where I is the electric current, and R is the electric resistance of the conductor. Iron losses associated with the conversion of electric energy into thermal energy in the iron. This loss consists of hysteresis and eddy current losses or Joule losses in the iron. Mechanical losses primarily related to the conversion of mechanical energy into thermal energy due to mechanical friction and viscous friction. Stray load losses are minor losses of which include losses related to skin effect and high frequencies, which are difficult to evaluate. Bousbaine [2] have studied the development of the thermal model of induction motors based on accurate loss density distribution to predict the temperature rise of a machine prior to construction. This study was taking into account the different material types and complicated geometries within the machine, as well as the different modes of heat transfer.

The conventional method of electric motor cooling is typically by using fins mounted on the outer surface of the motor housing. The fins serve to expand the surface area of the motor housing to increase the rate of heat transfer from the electric motor to the ambient air by convection. Installation of the fins is usually accompanied by the installation of the fan at one end of the motor shaft. The fan serves to draw air through the fins so as to increase the rate of convection heat transfer. Several studies have been conducted to improve the performance of the conventional thermal management of electric motors. Farsane et al. [3] conducted an experimental study on the cooling of a closed type electric motor. Li [4] proposed a design modification for performance improvements of cooling of a permanent magnet electric motor with a centrifugal impeller. Davin [5] conducted an experimental study on the use of lubricating oil as a coolant for electrical motors. For electric motors with high heat generation, some other technique can be applied to release the heat to the ambient air. One example is the electric motor cooling method using a cooling fluid flowed through a jacket placed between the stator and motor housing. The use of cooling liquid aims to improve the effectiveness of cooling of the electric motor. Lee [6] studied the development of a motor cooling system that employs a forced cooling method by providing channels for housing cooling and a hollow shaft for rotor cooling.

Heat pipes are thermal devices which have high heat transfer capacity with compact size and light weight, and they do not require any external power supply [7]. Putra et al. [8], [9], [10], Weng et al. [11], and Wang [12] have conducted studies on the use of heat pipes in the thermal management of electronic devices. Study on the use of heat pipes in the thermal management of an electric vehicle battery has also been conducted [13]. Putra et al. also conducted research on the development of the heat pipe capillary wick combined with nanofluid as the working fluid [14], [15], [16]. Their results showed that the combination of biomaterial wick and nanofluid working fluid enhances the thermal performance of heat pipes.

Currently, heat pipes are widely used in the thermal management of mobile devices such as laptops and mobile phones. Some of the inventions of the electric motor cooling using heat pipes have been patented. In some electric motor cooling applications, evaporator sections of heat pipes are placed inside the motor housing or buried in the motor shaft, while the condenser sections are placed outside the motor housing and cooled with circulated liquid or air stream.

Hasset et al. [17] through the patent with publication number US7569955 B2, dated August 4, 2009, entitled "Electric Motor with Heat Pipes," claimed an invention of the electric motor cooling method using straight heat pipes. In their invention, the evaporator side of the heat pipes is placed inside the motor housing, while the condenser side is placed in a cooling chamber containing a coolant which is circulated using a pump as shown in Fig. 1a. The drawback of this method is that the heat pipe is located inside the motor housing, so there is a risk for motor damage due to the heat pipe leakage. Moreover, the heat pipes are difficult to repair in case of damage. This method requires a special design to put the heat pipes in the electric motor housing. Also, this method requires some external power supply to circulate the coolant.

Owng et al. [18] through the patent numbered US 8368265 B2, published on February 5, 2013, entitled "Electric Motor Having Heat Pipes," claimed an invention of the electric motor cooling using straight heat pipes. They put the heat pipes around the motor shaft, the condenser of the heat pipes is placed on the impeller. The disadvantage of this method is that the heat pipes are located around the electric motor shaft so as to risk damaging the construction of the electric motor in the event of a leak. Moreover, the heat pipes are difficult to repair in case of damage. This method requires a special motor design to put the heat pipe around the electric motor shaft.

Rubby et al. [19] in the patent entitled "Cooling of an Electric Motor via Heat Pipes," publication number US 2014/0338857 A1, dated on November 20, 2014, also use straight heat pipes which the evaporator section installed in the motor housing and the condenser section placed in the cooling tank.

Fedoseyev et al. [20] through the patent numbered US 2014/0368064 A1, dated on December 18, 2014, entitled "Rotor Assembly with Heat Pipe Cooling System" claimed an invention on the electric motor cooling using straight heat pipes. They put the evaporator side of the heat pipe inside the shaft while the condenser side equipped with the cooling fins is placed outside the motor as shown in Fig. 1b. The disadvantage of this method is that the heat pipes are located within the shaft so that it can be a risky construction damaging the electric motor in the event of a leak. Moreover, the heat pipes are difficult to repair in case of damage. The motor shaft requires a special design to put the heat pipes inside the shaft.

In this study, the heat pipes are placed on the surface of the motor housing thus simplifying installation and maintenance. The objective of this study is to determine the performance of the electric motor thermal management system using L-shaped flat heat pipes experimentally.

Section snippets

Methods

The L-shaped flat heat pipes were made of flattened copper tubes with sintered copper capillary wick. Water was used as the working fluid with a filling ratio of 50%. Each heat pipe had evaporator section length of 154mm and condenser section length of 34mm as shown in Fig. 2. Heat sinks were mounted on each condenser section to increase the rate of heat transfer from the condenser section to the ambient air.

A prototype was made of a 0.5 HP conventional electric motor where the rotor and the…

Temperature and heat load measurement

The experiments were conducted in the laboratory at a temperature of 24 – 25°C. They started with a heat load of 30W. The heating was conducted until the steady state condition was achieved. About ten minutes after the steady state condition was achieved the heat load was increased to 60W. This procedure was repeated for the heat load of 90W, 120W, and 150W. The experiments were done twice, the first without using heat pipes, and the second by using heat pipes. Fig.8 shows the results of the…

Conclusions

The experiment to determine the performance of the electric motor thermal management system using L-shaped flat heat pipe has been conducted successfully. At the heat load of 150W, the outer surface temperatures of the motor can be decreased from 102.2°C to 68.4°C, or a decrease by 33.8°C. At the heat load of 150W, the thermal resistance from the motor fins with heat pipes and heat sinks to the ambient air can be reduced from 0.5°C/W to 0.28°C/W or a reduction by 44%. The use of L-shaped flat…

Acknowledgement

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