ICEMG 2020-XXXXX

The Experimental Heat Transfer Analysis on Rectangular and Triangular Fins in 3-Phase Asynchronous Electrical Motors

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Abstract
The experimental convection heat transfer between surface and fluid surrounding can be increased by attaching fins, and is governed by the Newton's cooling law. In this study, a two pole three-phase asynchronous medium voltage induction electrical motor (according to Std. ANSI C84.1-1989) with frame size of 400mm and 280kw power is considered that this induction electrical motor is designed, manufactured and tested in Jovain Electrical Motors Industries Company (JEMCO). The rectangular and triangular fins geometry are used for cooling system and the main target of this investigation is to find which type of these fins geometry is better in order to reach higher efficiency. The analyses demonstrates which the majority of convection heat transfer is occurred on the top edges and the variations of heat transfer with temperature and length, air velocity and pressure graph analyses show that the convection heat transfer in triangular fins have more efficiency than rectangular fins.

Keywords: induction electrical motors, rectangular and triangular fins, convection heat transfer, efficiency

Introduction

Heat transfer is an essential subject in all electrical motors companies to produce high performance electrical motors, so much budget and time are spent on researching and developing annually. It is highlighted that using fins as an auxiliary part on frames always transfers more heat. Here, the heat transfer by convection is considered as main mode and other two types of transfers are neglected. Also according to the shape, fins divided in several categories such as: rectangular fin, triangular fin, convex parabolic fin, trapezoidal fin, concave parabolic fin and cylindrical fin. In recent years, due to Analysis of fins performance of electrical motors has increased that some of them will be pointed in the following.

Mulamootil et al. [1] worked on natural convection heat transfer from horizontal fins by numerical investigations, the fluids that they used in their article was non-Newtonian fluids. Nikfar et al. [2] in their article studied on five different inverse shape design problems containing different types of convection heat transfer which are solved by the novel coupled algorithm. Kiwan et al. [3] discussed on using the porous fins to increase heat transfer for the first time. Kundu et al. [4] researched on porous fins with various cross sections, they presented that parabolic cross section has the most heat transfer among all kind of cross sections. Bhanja et al. [5] established an especial analytical model to analyze T-shaped porous fins. Many authors have studied on rectangular and triangular fins that mentioned in the following.

Gu-Won Lee et al. [6] investigated on thermal resistances of horizontal cylinders with triangular fins were measured in regard to fin numbers, fins heights, and temperature differences. But they don't study on other fin geometries. Falcao et al. [7] investigated to optimization of rectangular fins with prime surface and bottom convection. Arora et al. [8] provided an introduction and boundary conditions for triangular fins and analyzed them. Narve et al. [9] studied on effects of natural convection heat flow through vertical symmetrical triangular fin arrays on heat transfer experimentally. They also worked on relations between Nusselt number and Grashoff number entirely. Kumar et al. [10] studied on experimental investigation to forecast the performance of heated vertical triangular fin array in various Rayleigh number, fin spacing and fin height. Mirapalli et al. [11] worked on heat transfer in an air cooled engine by triangular fins; they considered various temperature and length for engine cylinder. Raseelo et al. [12] did a 2-D survey on a rectangular straight fin.

This paper is a part of national technology transfer project of induction electrical motor propulsion system design. In this study, the three-phase asynchronous induction electrical motor (according to Std. ANSI C84.1-1989) with frame size of 400mm and 280kw power is designed and manufactured in the Jovain Electrical Motors Industries Company (JEMCO) and tested in its laboratories, the international protect (according to Std. IEC60034-5 is IP55), international mounting (according to Std. IEC60034-7 is IM1001) and the international cooling (according to Std. IEC60034-6 is IC411). The frequency and voltage are 50Hz and 6600V respectively. The rectangular and triangular fins geometry are comparing for cooling system and introduce which type of these fins is better to reach higher efficiency. The results are useful in designing forced convection systems that employ air to enhance the heat transfer.

Solution Method

For rectangular fins with (L) as the length of the fin, (t) as thickness of the fin and (W) as width of fin. The main characters of rectangular fins are shown in "Figure 1".
Heat lost by a rectangular fin with this supposition that heat transfer coefficient is constant during heat transferring is defined as "Equation1".

$$Q_r = kA_c m\theta_0 \frac{h + km\tanh(mL)}{km + h\tanh(mL)} \quad (1)$$

Where k $(\frac{W}{mK^o})$ is thermal conductivity, $A_c(m^2)$ is fin cross section area, m is defined as $\sqrt{hp/KA_c}$, P (m) fin cross section perimeter, $\theta_0(K^o)$ is temperature difference and heat transfer coefficient is defined by h $(\frac{W}{m^2.K^o})$.

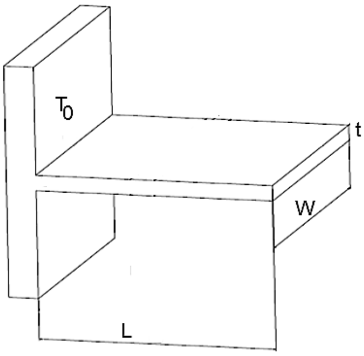

Figure1. Main characters of rectangular fin

Due to the "Equation 2" fin efficiency is defined as the ratio of the heat transferred through a real fin to that transferred through an ideal fin. An ideal fin is one made of a perfect or infinite conductor material. A perfect conductor has an infinite thermal conductivity so that the entire fin is at the base temperature.

$$\eta = \frac{-kA_c m\theta_0 \frac{h + km\tanh(mL)}{km + h\tanh(mL)}}{2WLh\theta_0} \quad (2)$$

In "Equation 3" for an adiabatic fin the effectiveness is defined as how effective a fin can increase heat transfer which is as the ratio of fin heat transfer to the heat transfer without fin.

$$\varepsilon_r = \frac{-kA_c m\theta_0 \frac{h + km\tanh(mL)}{km + h\tanh(mL)}}{hA_c\theta_0} \quad (3)$$

For triangular fins with (L) as the length of the fin, (t) as thickness of the base of fin and (W) as width of fin with this supposition that heat transfer coefficient is constant during heat transferring. The main characters of triangular fins are shown in "Figure 2".

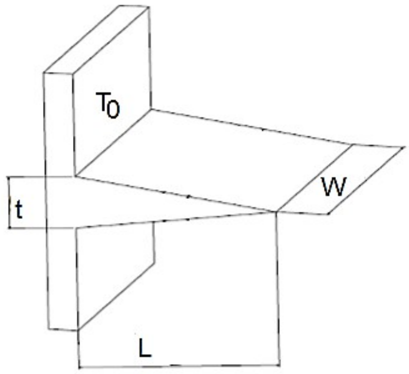

Figure2. Main characters of triangular fin

Heat loss by a triangular fin is defined as "Equation 4".

$$Q_t = W\theta_0\sqrt{2(hkt)}\left[\frac{I_1(2L\sqrt{\frac{2h}{kt}})}{I_0(2L\sqrt{\frac{2h}{kt}})}\right] \quad `(4)$$

Where k $(\frac{W}{mK^o})$ is thermal conductivity, $\theta_0(K^o)$ is temperature difference and I_1 and I_0 are first kind Bessel function. Efficiency and effectiveness of triangular fins are demonstrated as "Equations 5 and 6" respectively.

$$\eta_t = \frac{W\sqrt{2hkt}\,\theta_0 (\frac{I_1\left(2L\sqrt{\frac{2h}{kt}}\right)}{I_0\left(2L\sqrt{\frac{2h}{kt}}\right)})}{2WLh\theta_0} \quad (5)$$

$$\varepsilon_t = \frac{W\sqrt{2hkt}\,\theta_0 (\frac{I_1\left(2L\sqrt{\frac{2h}{kt}}\right)}{I_0\left(2L\sqrt{\frac{2h}{kt}}\right)})}{h.A_b.\theta_0} \quad (6)$$

Where $A_b(m^2)$ is base area.

Result and Discussion

This medium voltage Induction electrical motor with certain electrical and mechanical features that mentioned is manufactured in two designs; first design with triangular fins and gray cast iron frame (according to the Std. DIN: GG20) and another one with rectangular fins and structural steel frame (according to the Std. DIN: S235JR). Length, width and cross section of fins in both electrical motors are equal. For better casting and having higher heat transfer, a circular symmetric fillet at the end edges of triangular fins is considered. All results in this study are comparative and dimensionless. All experimental tests on JEMCO laboratories are done by expert technicians in same and steady ambient conditions. Also, a complete record of testing process and test reports data are field and saved in the quality control department. All heat losses in electrical motors such as iron loss, mechanical loss, stator and rotor copper loss and additional loss in these two electrical motors are calculated exactly. The total loss for both electrical motors is 17.061KW."Figure 3and 4" show the schematics of these two kinds of fins. Also, "Figure 5" shows these fins on real electrical motors.

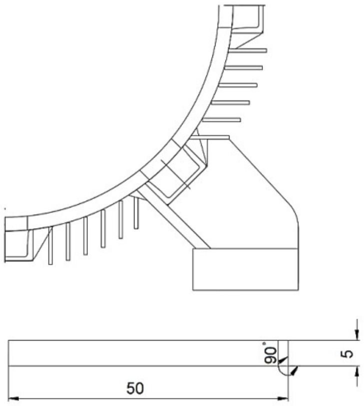

Figure3. Schematics rectangular fins

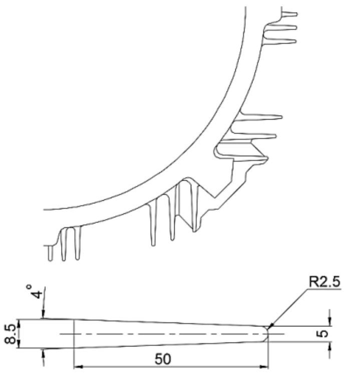

Figure4. Schematics triangular fins

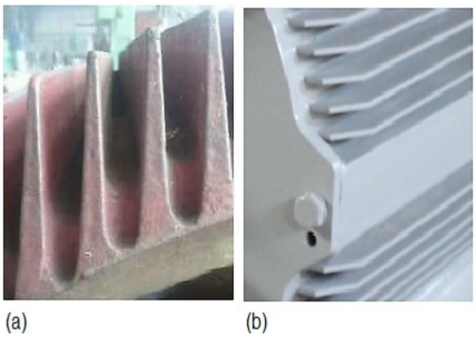

Figure5. (a). The manufactured triangular fins,
(b). The manufactured rectangular fins

Two electrical motors with structural steel frame and cast iron frame which have been chosen for this survey are demonstrated in "Figure 6". Main losses in electrical motor which included rotor iron loss, stator iron loss, mechanical loss, stator copper loss and additional loss are depicted in "Figure 7".

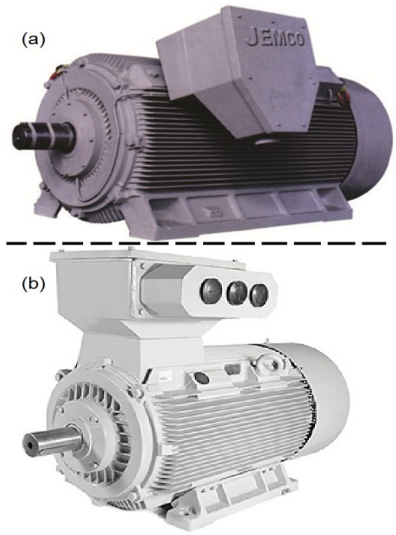

Figure6. The three-phase induction electrical motors designed and manufactured in JEMCO (a). Gray cast iron frame, (b).Structural steel frame.

All direct load method temperature rise tests have been done in December, the ambient temperature is between 12C° and 11.3C°.The ambient humidity is 53%. Temperature on frame and fins is evaluated by the infrared thermometer VA6530- class2 and at the first, it is 12C°. Temperatures are recorded every 30 minutes in six steps until they reach to the fix values finally. According to Std. IEC85 the insulation class of these electrical motors are B, which means the maximum winding temperature is 40C° and permissible temperature rise is 80C°.

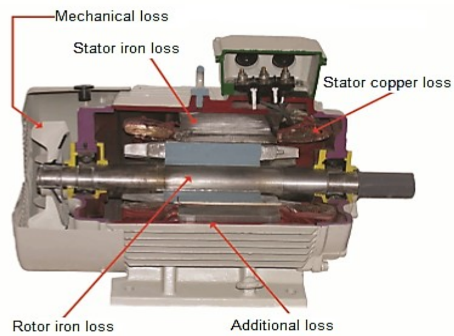

Figure7. An electrical motors losses sample

According to the fin equations and by considering ideal condition for both fins two below graphs are concluded, all values are dimensionless. "Figure 8" demonstrates variation of heat transfer with temperature changes; it is observed that there is a keen increase of fins heat transfer. This parameter in triangular fins is more than rectangular fins. "Figure 9" shows the variation of heat transfer in comparison with length changes. It is noted that as the length is raised, heat transfer increases. However, triangular fins give more heat transfer compared to rectangular fins.

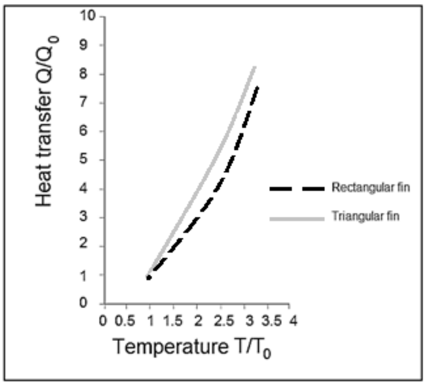

Figure8. Variation of heat transfer (Q/Q0) with temperature (T/T0)

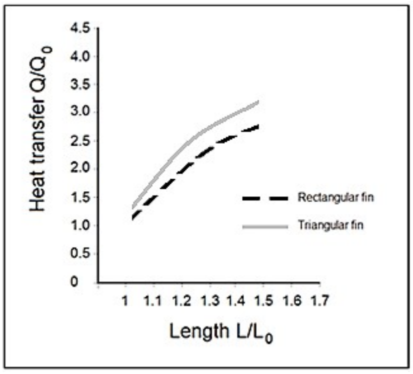

Figure9. Variation of heat transfer (Q/Q_0) with length (L/L_0)

In "Figure 10" the air flow velocity on rectangular and triangular fins on the stable modes is shown. It specifies that air maximum velocity and average velocities between two adjacent triangular fins are more than air velocity in gap of two adjacent rectangular fins. So heat transfer by convection in similar conditions is increased in triangular fins. The impact of the length on the air velocity between two triangular fins is shown in "Figure 11", it shows that by increasing the fin length the air velocity on the top edge of the fin and air average velocity increased and air maximum velocity decreased, finally the heat transfer enhanced. Total pressure difference between rectangular and triangular fins that proves the verity of Figure 10is demonstrated in "Figure 12".

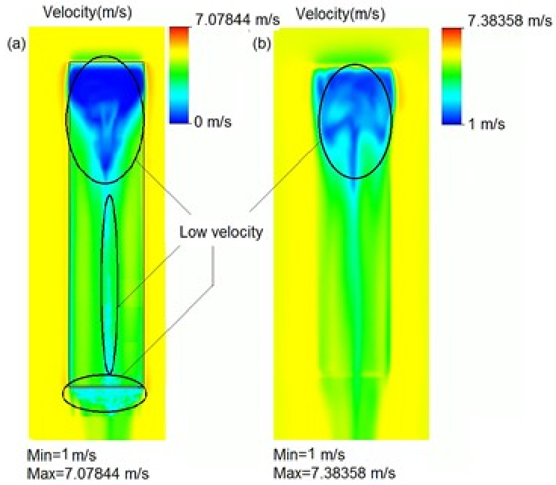

Figure10. Air velocity graph with 50 mm length
(a). Rectangular fins, (b). Triangular fins

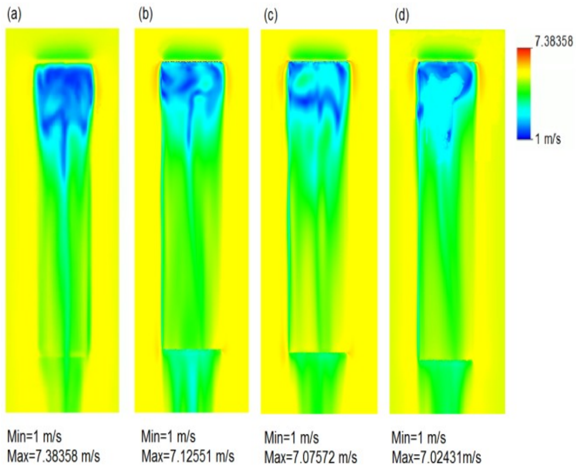

Figure11. Length impact on air flow velocity between two adjacent triangular fins, (a). L=50mm, (b). L=60mm, (c). L=70mm and (d). L=75mm

The higher velocity of crossing air flow on the top edge of triangular fins especially in non-drive end of electrical motors where the external fan is inserted, is shown in "Figures 13 and 14". These figures demonstrate that the noticeable amount of convection heat transfer occurred via the fins top edges.

Rated load type test of these two electrical motors in laboratories shows that final frame temperature with triangular fins is 69C^o and final frame temperature with rectangular fins in this type of electrical motors is 75.8C^o,Due to the rectangular fins are made by welding process that cause of the existence of air gap, these air gaps are less than 1mm, there is fewer tolerance between experimentally and numerically results, based on the ultrasonic tests, the final frame temperature in ideal conditions would be about 73.5C^o. In according to the total heat transfer coefficients of gray cast iron (Std. DIN: GG20) and structural steel (Std. DIN: S235JR) in free air environment, 5.4 and 7.9 $\frac{W}{m^2.K^o}$ respectively, this result can be concluded that triangular fins have better efficiency.

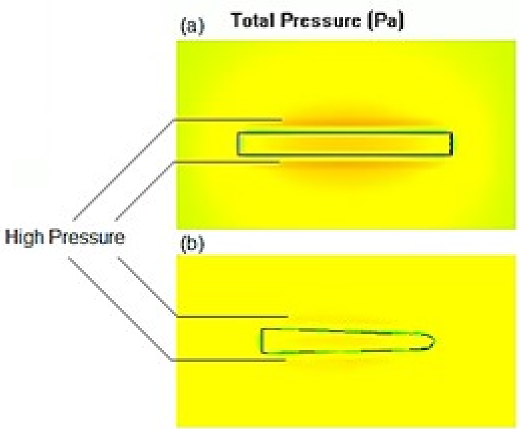

Figure12. Pressure graph on the (a). Rectangular fins, (b). Triangular fins.

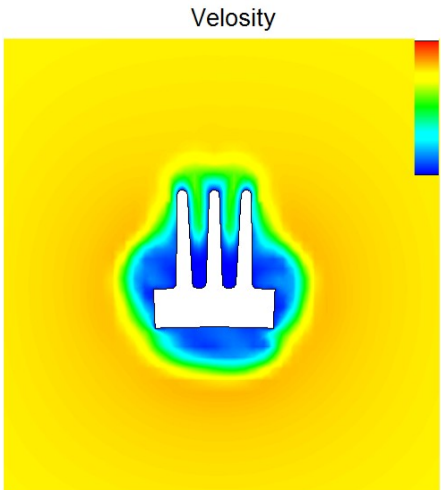

Figure13. Air flow velocity on triangular fins

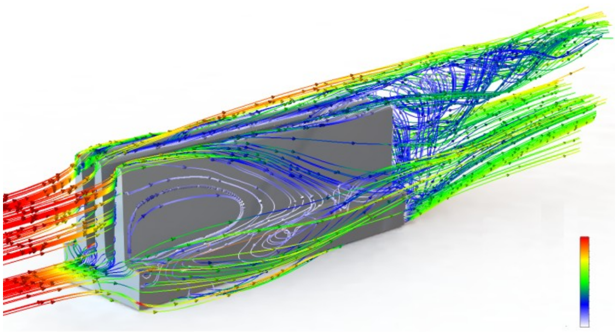

Figure14. Air flow trajectories on triangular fins

Conclusion

In this study, the experimental analysis of rectangular and triangular fins on two types of three-phase 2pole asynchronous medium voltage induction electrical motors are investigated and compared. Air maximum and average velocities on triangular fins are more than rectangular fins. So, heat transfer convection on triangular fins are increased. The impact of length on air velocity between two triangular fins it makes air average velocity increased and air maximum velocity decrease.
Varying the length of fin from 50mm to 75mm caused about 45% more heat transfer growth in triangular fins in comparison with rectangular fins. The majority of convection heat transfer is occurred on the top edges. Length increasing in triangular fins leads more air average velocity and finally more convection heat transfer so causes more efficiency. This study proves that triangular fins are more suitable than rectangular fins in cooling the electrical motors via natural convection heat transfer; this result is attained from experimental analysis too.

Acknowledgement

The authors thank the Jovain Electrical Motors Industries Company (JEMCO) for supporting this project and our colleagues who support this study technically. I first kind Bessel function

NOMENCLATURE

L	Length	P	fin cross section perimeter
t	thickness	θ_0	temperature difference
W	width	h	heat transfer coefficient
K	thermal conductivity	Q_r	heat transfer
P_a	pressure	η	efficiency
A_c	fin cross section area	ε_r	adiabatic effectiveness
Q_t	heat loss	I	first kind Bessel function
A_b	base area		

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