Finned Electric Motor with Prescribed Heat Flux and Influence of the Internal and External Heat Convection Coefficients on the Temperature of the Core

Marcus Vinicius Ferreira Soares and Élcio Nogueira

1 Rio de Janeiro State University

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Abstract
One of a major objective is to analyze the effect of internal and external convection coefficients in the heat transfer generated by electric motors and characterize intervals of feasible values, in practical terms, for these coefficients. Another objective is to determine the motor core temperature, considering the environmental and operational conditions of the motor installation and the heat flux $Q_0$ (fixed) in the fins. To achieve the objectives were developed analytical solutions for determining the temperature variations in the fins, performance and electric motor efficiency, considering heat flow constant at the base of the fins and the possible variations in temperature of surround media. The heat flux at the base of the fins, in this case, is the minimum necessary for satisfactory electric motor performance and the core temperature is within the safety range stipulated by the manufacturer. The obtained results characterize a range of possible values for the inner and outer heat transfer coefficients.

Index terms — finned electric motor; constant heat flow; efficiency; efficacy.

1 Introduction
Factors that allow electric motors to lose up to 4% of their performance over their lifetime are improper installations, lack of regular maintenance, cleanliness and quality lubrication [Cardoso et. Al., 2009]. Therefore, overheating the electric motor and consequently burning it is a problem for maintenance personnel, since heat produced by the electric motor must be dissipated efficiently, avoiding overheating and consequent burning. The high temperatures of the installation environment and the inefficient heat dissipation generated by the difference in net power supplied by the motor and power absorbed in the line is the main cause of overheating (Santos, Rafael Simões, 2011).

Fins or the extended surfaces are extensively used in engineering applications to increase the heat transfer efficiency of surfaces, and are of vital importance in the design of heat exchange devices in different fields of applications in order to provide an enhanced heat transfer effect through an increase in the total heat exchange area (Campo, A.; Kundu, B., 2017), [Incropera, Frank P. Et Al., 2008], (Santos, T. A. M., 2017). Once the temperature distribution through the fin is known, the heat transfer rate and the efficiency can be readily determined.

In electric motors, it is common to use extended surfaces, which increase the exchange area as a mechanism for heat transfer optimization. In fact, an important industrial application of fins occurs in electric motors and are of vital importance in the industry as they are used in machines of all types, including, for example, computer ventilation and other electronic equipment. A well-dimensioned finned ventilation system can contribute to energy savings.

The heat dissipation is directly associated with efficient ventilation, the temperature difference between the engine housing surface and the medium (in this case, the air surrounding the engine), the total heat exchange
3 RESULTS AND DISCUSSION

We analyzed the temperatures ambient strictly below 45°C for cast iron and aluminum materials. The data in Table 2 and Figure ??, related to the internal and external heat transfer coefficients, show that under the best possible condition [h_2 = 1000 W / (m^2°C)], there is no considerable difference between the analyzed materials.
For analysis purposes, a maximum engine core working temperature of 98 °C is assumed. The manufacturer sets
the maximum operating temperature equal to 120 °C.

Analyzing Figure ?? for the external temperature of 40 °C, we have that, for Cast Iron the motor to work in
the acceptable temperature range, the value of h 2 must be greater than or equal to 200 W/ (m ². °C).

For the value of h 1 = 200 W/ (m ². °C), shown in Figure ??, the motor works at the limit established in the
research and we can conclude that the motor works properly for values of h 1 above 200 W / (m². ° C).

Analyzing Figure ??, for the external temperature of 40 °C, we arrive at the following conclusions: for h 1
= 100 W / (m². ° C) the motor temperature is equal to 128.61 °C, which goes beyond the limit value. From
research of 98 °C. In the same ??, for h Figure ??, is the graph constructed from the data generated for
engine efficiency. Note how aluminum results are far superior to cast iron. ?? ?????????? = ?? 0 ° 2 . [?? ?? +
(?? ????????? ? 32 . ?? ?? )] . (?? ?? ? ?? ?) 25

Another parameter to be analyzed is the effectiveness of the engine, which is the ratio between fin and non-fin
motor heat exchange. The efficacy formula given by: ?? ?????????? = ?? 0 ? 2 . ?? ?????????? . (?? ?? ? ?? ?
)26

Again, Figure ??, demonstrates that the results for aluminum are much higher than those obtained by cast
iron.

Looking at Figure ??, we can conclude that a reasonable effectiveness value for a fin of 2.5 is achieved when
h 2 is near 400 W / (m². ° C) for cast iron.

Based on the results observed above, and in the graphs of efficiency and effectiveness, we conclude that for any
values of h 1 ? 200 W / (m². ° C) and h 2 ? 200 W / (m². ° C) the engine temperature will have a satisfactory
value. However, the values of h 1 and h 2 are physically limited. For h 1 to assume values greater than 400 W
/ (m². ° C), forced ventilation must be used with the aid of a fan inside the engine or by drilling holes in the
housing to increase natural ventilation. In addition, for h 2 to assume values greater than 400 W / (m². ° C),
ventilation must be increased in the environment where the engine is installed, which would generate more costs
for the company.

The above results are consistent with the results presented and experimentally confirmed by Micallef (2006),
using experimental and numerical method CFD - Computation Fluid Dynamic, the author applied three distinct
turbulence models, and the results showed that the closer to the motor core, the higher the heat transfer coefficient
by convection acting on the internal surfaces.

The measured internal coefficient assumed values close to 300 W / ( m² .K), a value that is included in the
working range proposed by this study.

IV.

4 CONCLUSION

The motor core temperature was computationally simulated by varying the internal (h 1 ) and external (h 2 )
convection heat transfer coefficients and the ambient temperature. The results demonstrated two things: the
importance of the internal heat transfer coefficients and their physical limitations.

Regarding the heat transfer coefficients, we can conclude that the values of h 1 and h 2 cannot be treated
separately. For very low h 1 and h 2 values the fins tend to be at the same temperature as the outside temperature,
so there is no efficient heat exchange, overheating the engine. For very high h 1 values, which is physically
impossible to obtain, we have that the fin base tends to stay with the motor core temperature, with is the usually
conditions generally used by the one-dimension and two-dimension fin models.

We conclude that for any values of h 1 ? 200 W/ (m². ° C) and h 2 ? 200 W / (m². ° C) the motor temperature
will have a satisfactory value. However, as already mentioned, the values of h 1 and h 2 are physically limited.
For h 1 to assume values greater than 400 W / (m². ° C), which is already a critical value to obtain for mechanical
reasons, it is necessary to use forced ventilation inside the engine or drill holes in the housing to increase natural
ventilation. The same reasoning can be used for the external coefficient h 2 , which would entail a higher cost to
the company, as it would be necessary to increase ventilation at the engine installation site.

Thus, the ranges, 200 ? h 1 ? 300 and 200 ? h 2 ? 400, are the limit values that guarantee the lowest value for
the heat transfer rate required for efficient heat removal. Any values above these will increase the transfer rate
and consequently decrease the motor core temperature, however, considering the difficulties of achieving these
values in practical terms. [1]
### CONCLUSION

| Power | 1 cv |
|-------|------|
| Number of Poles | 4 |
| Motor Outer Diameter | 139,60 mm |
| Engine Width | 130,13 mm |
| Number of Fins | 32 |
| Fin Base Width | 5,84 mm |
| Fin Height | 17,00 mm |
| Maximum Ambient Temperature | 40 °C |

Figure 1: 29 Year 2019 Finned

![Graph showing Motor Core Temperature vs. Internal Convection Heat Transfer Coefficient](image)

Figure 2: Figure 1:
Figure 3: Figure 2: Figure 4:
Figure 4:
Figure 5:

Cast Iron

1 - $T_{\text{inf}} = 15^\circ \text{C}$
2 - $T_{\text{inf}} = 20^\circ \text{C}$
3 - $T_{\text{inf}} = 30^\circ \text{C}$
4 - $T_{\text{inf}} = 40^\circ \text{C}$

$h_2 = 100 \text{ W/(m}^2\text{C})$
Figure 6:

- Cast Iron
- $T_{inf} = 15^\circ C$
- $T_{inf} = 20^\circ C$
- $T_{inf} = 30^\circ C$
- $T_{inf} = 40^\circ C$

$h_2 = 200 \text{ W/(m}^2\text{C)}$

Motor Core Temperature - $T_m^\circ C$

Internal Heat Transfer Coefficient - $h_1 \text{W/ (m}^2\text{C)}$
Figure 7:

Figure 8:
Figure 9:
| h1 (W/(m²·°C)) | ?? °C Al | ?? °C Al | ?? °C Al | ?? °C Al |
|-----------------|---------|---------|---------|---------|
| Iron Cast       | 93.86   | 93.40   | 98.86   | 98.40   | 108.86  | 108.40  | 118.86  | 118.40  |
| 100             | 68.16   | 67.70   | 73.16   | 72.70   | 83.16   | 82.70   | 93.16   | 92.70   |
| 150             | 55.31   | 54.85   | 60.31   | 59.85   | 70.31   | 69.85   | 80.31   | 79.85   |
| 200             | 47.60   | 47.14   | 52.60   | 52.14   | 62.60   | 62.14   | 72.60   | 72.14   |
| 250             | 42.46   | 42.00   | 47.46   | 47.00   | 57.46   | 57.00   | 67.46   | 67.00   |
| 300             | 38.79   | 38.33   | 43.79   | 43.33   | 53.79   | 53.33   | 63.79   | 63.33   |
| 350             | 36.04   | 35.58   | 41.04   | 40.58   | 51.04   | 50.58   | 61.04   | 60.58   |
| 400             | 33.90   | 33.43   | 38.89   | 38.43   | 48.89   | 48.43   | 58.89   | 58.43   |
| 450             | 32.18   | 31.72   | 37.18   | 36.72   | 47.18   | 46.72   | 57.18   | 56.72   |
| 500             | 30.78   | 30.32   | 35.78   | 35.32   | 45.78   | 45.32   | 55.78   | 55.32   |
| 550             | 29.61   | 29.15   | 34.61   | 34.15   | 44.61   | 44.15   | 54.61   | 54.15   |
| 600             | 28.62   | 28.16   | 33.62   | 33.16   | 43.62   | 43.16   | 53.62   | 53.16   |
| 650             | 27.78   | 27.32   | 32.78   | 32.32   | 42.78   | 42.32   | 52.78   | 52.32   |
| 700             | 27.04   | 26.58   | 32.04   | 31.58   | 42.04   | 41.58   | 52.04   | 51.58   |
| 750             | 26.40   | 25.94   | 31.40   | 30.94   | 41.40   | 40.94   | 51.40   | 50.94   |
| 800             | 25.83   | 25.37   | 30.83   | 30.37   | 40.83   | 40.37   | 50.83   | 50.37   |
| 850             | 25.33   | 24.87   | 30.33   | 29.87   | 40.33   | 39.87   | 50.33   | 49.87   |
| 900             | 24.88   | 24.42   | 29.88   | 29.42   | 39.88   | 39.42   | 49.88   | 49.42   |
| 950             | 24.47   | 24.01   | 29.47   | 29.01   | 39.47   | 39.01   | 49.47   | 49.01   |

Figure 10: Table 2:
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