Analytical investigation of copper substrate fins of various profiles for heat transfer applications

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1. Introduction

Heat transfer is a process that has significant application in day to day life as well as a wide range of industrial implications. All mechanical devices develop heat as they function due to energy interactions. This induces a need for effective heat dissipation in such devices. A sizeable amount of research has been done into the topic. Examples are Pardeep Singh et al., [1] who tested upon the effects of varying simple geometrical profiles. They conclusively prove that there are other profiles that have a better heat transfer efficiency than traditionally used rectangular profiles. Roody Charles & Chi-Chuan Wang [2] have published a paper which compares the effectiveness of a regular trapezoidal fin, a traditional rectangular fin and an inverted trapezoidal fin. It proves beyond doubt that the inverted trapezoidal fin is the most effective of all the fin profiles compared. Ong et.al., [3] prove that using forced convection is more effective than natural convection for better heat transfer characteristics. The paper published by A. Morales-Fuentes & Y.A. Loredo-Sáenz [4] demonstrates that surfaces with a high Surface Area to Volume Ratio are preferred. As such we may theorize that varying the profiles of the fin results in improved thermal properties.

Abstract. Fins are surfaces that extend from an object to increase rate of heat transfer by increasing surface area. Traditionally, fin profiles have been rectangular in shape. However, in recent years a trend has emerged where fin profiles have been designed in a variety of shapes in order to maximize heat dissipation properties. Here different fin profiles (both symmetrical and non-symmetrical) will be designed using modelling software and the temperature drop across the fin surface will be monitored in order to study the heat dissipation effectiveness of each fin profile. The analysis is done using Finite Element Analysis Software.

Keywords. Fins, Heat Transfer, Copper, FEA, Temperature Drop, Effectiveness
2. Methodology

2.1 Design

Designing was done using SOLIDWORKS software using sketching and feature based commands in order to create dimensionally accurate models for the FEA stage. The designs are shown from Figure 1 to Figure 4. The designs were based on certain criteria derived from existing literature.

2.1.1 Design Criteria. The criteria used were

1. The Surface Area to Volume Ratio must be high.
2. The number of sharp edges, which serve as heat dissipation zones, must be maximized.
3. The Surface Area & Thickness must be kept constant.
4. One profile must be a rectangular base profile to which all others will be compared.

![Diagram of Rectangular Fin Profile](image)

Figure 1. Rectangular Fin Profile
Figure 2. Triangular Fin Profile

Figure 3. Inverted Trapezoidal Fin Profile
2.2 Finite Element Analysis

FEA was done in ANSYS R19 Student Edition software using the Fluent Workbench. The various steps are:

2.2.1 Geometry. The model is either redesigned or imported into the software interface using a standard data format like STEP or IGES.

2.2.2 Mesh. Mesh properties such as sizing and element type are determined in order to divide the fin model into finite elements for accurate analysis. Here the mesh element type used is tetrahedral and minimum mesh size used is 2mm.

2.2.3 Setup. Once the mesh is generated, boundary conditions need to be specified. Energy equation is enabled in order to conduct heat based calculations; Cell zone conditions are provided which is where material for solid (Copper) and fluid (Air) are mentioned; Boundary conditions for every part of the solid, fluid and the solid-fluid interface are entered (Base Temperature – 90°C, Air Velocity – 2m/s, Coupled interface for heat transfer); Solution is initialized (Number of iterations – 100, Hybrid initialization, Absolute values, Constant velocity magnitude maintained); Calculation is run (Number of iterations – 100)

2.2.4 Solution. Results are obtained and contours are plotted with colour indication of required heat parameters (Temperature Distribution)

2.3 Verification of Results Experimentally

After the design and analysis procedure is completed, the fin profiles can be manufactured using stir casting method. Stir casting can either be done manually or automatically depending on the availability of equipment and the amount of mixing precision required. Depending on number of pieces needed, blanks are to be casted. Die or molding cost can be saved by having single blank size for all profiles. Once casted, the actual shape of the fin is cut using Wire Cut Electrical Discharge Machining which provides very high
dimensional accuracy and smooth surface finish. Further machining is done after wire cutting if required and the fins are prepared for testing. Testing for heat transfer characteristics can be performed using forced convection heat transfer apparatus. Each specimen is to be given the same base temperature and constant air velocity, following which various thermal parameters are to be measured. Results are then compared to the obtained analytical calculations.

3. Analytical Results

Figure 5. Temperature distribution of Rectangular Fin Profile
Figure 6. Temperature distribution of Triangular Fin Profile

Figure 7. Temperature distribution of Inverted Trapezoidal Fin Profile
4. Conclusion

Based on the results of the FEA done, we can observe that the Non-Symmetrical fin profile has the best temperature dissipation followed by the Triangular fin profile and the Trapezoidal fin profile. It can be concluded that the profiles selected can be used as more effective alternatives to the traditional Rectangular fin profile.

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6. References

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