Propulsion and Power Research 2016;5(1):55–62

HOSTED BY ELSEVIER

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com

ORIGINAL ARTICLE

Numerical investigation for a hyperbolic annular fin with temperature dependent thermal conductivity

M.T. Darvishi[a], F. Khani[a,*], Abdul Aziz[b]

[a]Department of Mathematics, Razi University, Kermanshah 67149, Iran
[b]Department of Mechanical Engineering, School of Engineering and Applied Science, Gonzaga University, Spokane, WA 99258, USA

Received 19 January 2015; accepted 7 July 2015
Available online 23 February 2016

KEYWORDS

Hyperbolic annular fin;
Thermal performance;
Pseudospectral method

Abstract An annular fin of hyperbolic profile with temperature dependent thermal conductivity is studied by pseudospectral method. Graphs illustrating the effect of fin dimensions, surface convection characteristics and the thermal conductivity parameter on the thermal performance of the fin are presented and discussed. A comparison of the obtained numerical results is made with the closed form analytical solution available in the literature for the case of constant thermal conductivity. This comparison confirms the high accuracy of numerical results. When the thermal conductivity increases with temperature, the effect is to elevate both the temperature distribution in the fin and the fin efficiency. The converse is true when the thermal conductivity decreases with temperature.

1. Introduction

Radial (annular) fins are often attached to the cylindrical surfaces to increase the rate of heat transfer from the cylindrical surface to the ambient. Traditional applications have included internal combustion engines, compressors, heat exchangers and control systems. With the advent of space age, space radiators equipped with annular fins of triangular profiles became popular. For example, Schnurr and Cothran [1] used a finite difference approach to study fin-and-tube radiator fitted with annular fins of triangular and trapezoidal profiles and included these effects in their analysis for the fin-to-fin and fin-to-base radiative exchange.

*Corresponding author. Tel.: +98 9124984928.
E-mail address: farzad_khani59@yahoo.com (F. Khani).

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

http://dx.doi.org/10.1016/j.jppr.2016.01.005

Design charts were produced to allow the calculation of heat dissipation for various values of the radiation parameter and the fin radii ratio. In the last thirty years, the use of fins as heat sinks for cooling electronic devices has gained enormous popularity. An earlier design used a capped hollow tube as a transistor heat sink [2,3] in which the cap serves as a radial fin. The analysis involved simultaneous solution of the two fin equations, one for the hollow tube and the other for the cap. Expressions were derived for the dissipation and fin efficiency of the proposed design. A web based analysis tool has been provided by HYPERLINK http://www.electronics-cooling.com/author/p/_teertstra by P. Teertstra et al. [4]. This tool allows the performance evaluation of a convective heat sink made of annular fins of rectangular profile as a function of the geometry, material properties, and the boundary and ambi ent conditions. More recent designs based on the constructal theory [5] appear in the form of a tree-like structure consisting of radial fins of different outer radii mounted on a tube [6]. This design minimizes the thermal resistance between the base of the fin and the environment. However, such a design is expensive to manufacture and hence difficult to implement in practice. The use of radial fins on condensers in refrigeration units is also very common. Condensers of thermosyphons used to stabilize foundations built on permafrost are equipped with radial fins to enhance dissipation of ground removed heat to the environment [7]. The subject of design and analysis of radial fins is a part of a wider body of knowledge called the extended surface heat transfer with contributions from a vast number of research ers throughout the world. The work done on radial fins until the year 2000 has been comprehensively discussed in a treatise by Kraus et al. [8]. The research work on radial fins has continued unabated in the last 10 years. Mokheimer [9] studied the effect of temperature dependent heat transfer coefficient, h, on the efficiency of annular (radial) fins of rectangular, triangular, concave parabolic and convex para bolic profiles and compared his finite difference results with those of Ullmann and Kalman [10] who used a constant h. Mokheimer concluded that the assumption of constant h leads to a significant underestimation of the fin efficiency. The use of his graphs reduces the amount of fin material required for a given heat transfer duty. Motivated by the savings in material, Kundu and Das [11] considered an annular fin with a step change in thickness and gave analytical results for the thermal performance as well as optimum dimensions of such a fin geometry. They found that a step annular fin provides higher heat dissipation with lesser material when compare with an annular fin of uniform thickness. It was suggested that a multiple step design instead of a single step could be used if further improvement in heat transfer and/or a reduction in the amount of material was necessary. Such a multiple-step design would be more difficult and expensive to fabricate and may not be economically feasible in practice. Soylemez [12] performed a thermo-economic analysis for a pipe with radial fins and derived the optimum length of the pipe that gave the maximum savings from a finned pipe for waste heat recovery applications. Chiu and Chen [13] calculated the thermal stresses induced in an annular fin with variable thermal conductivity due to a periodic variation of its base temperature. They found that the maximum radial stress in the fin occurred at a radial distance of 30% of the fin height (difference between the tip and base radii), while the maximum tangential stress occurred at the base of the fin. Unless fins are used in applications involving large tem perature differences, thermal stress calculations may not be warranted. Kang and Look [14] presented an optimization study of an annular fin of trapezoidal profile. Their results allow the designer to establish the optimum dimensions of the trapezoidal fin for a given volume of the fin material. Papers by Arslanturk [15] and Kang and Look [16] focus on annular fins with different heat transfer coefficients on the top and the bottom and present the performance and optimization results when an annular fin is subjected to asymmetric thermal conditions on its two faces. Such asymmetric thermal conditions can occur in horizontally oriented fins under natural convection conditions. In prac tice, if an average of the heat transfer coefficients on the two faces of the fin is used, it often obviates the need for more complicated analyses given in [15,16]. The works of Kundu [17], Sharqawy and Zubair [18], and Rosario and Rahman [19] deal with the performance and optimization issues when a single or an assembly of annular fins operates under dehumidifying conditions. These analyses involve simulta neous heat and mass transfers from the surface of the fin. For a fully wet fin, Sharqawy and Zubair [18] reported that the overall fin efficiency decreases as the relative humidity increases and as the atmospheric pressure decreases. The efficiency of a wet fin was found to be lower than that of a dry fin. Kundu [17] emphasized that for a given amount of material, an annular fin with a step change in thickness also provides superior thermal performance under wet condi tions when compared with the performance of a uniformly thick fin. Aziz and McFadden [20] used a symbolic algebra package to obtain an analytical solution for the temperature distribution in a heat generating annular fin with a constant base heat flux and an adiabatic fin. The analytical solution which appeared in terms of the modified Bessel functions can be used to compute the unknown base temperatures when other pertinent quantities are specified. In an earlier study, Yovanovich et al. [21] analyzed a heat generating annular fin with convective boundary conditions at both ends of the fin, taking into account the contact resistance at the base of the fin. As expected, the presence of contact resistance and the convection resistances at the two ends of the fin significantly impacts the thermal performance of the fin. The second law based optimum design of an annular fin has been reported by Taufiq et al. [22]. Their analysis included the entropy generation due to heat transfer as well as entropy generation due to fluid friction associated with the external flow over the surface of the fin. An entropy