Applied Thermal Engineering 70 (2014) 131–138

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Improved radial heat sink for led lamp cooling

Vítor A.F. Costa [a,*], António M.G. Lopes [b]

[a] Departamento de Engenharia Mecânica, Universidade de Aveiro, Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
[b] ADAI-LAETA, Departamento de Engenharia Mecânica, Universidade de Coimbra, 3030-788 Coimbra, Portugal

HIGHLIGHTS

- A numerical study is made concerning the radial heat sink for a specific LED lamp.
- The cylindrical heat sink is obtained from an extruded aluminum bar.
- The required cooling effect is obtained using the minimum mass of material.

ARTICLE INFO

Article history:
Received 9 July 2013
Accepted 25 April 2014
Available online 10 May 2014

Keywords:
LED lamps
Heat sink
Thermal performance
Natural convection heat transfer
Conjugate heat transfer

ABSTRACT

This paper presents a numerical study concerning an improved heat sink for a light emitting diodes (LED) lamp operating under natural convection conditions. Basic geometry of the heat sink is of cylindrical nature, to be obtained from cutting an aluminum extruded bar comprising a cylindrical central core and a number of uniformly distributed radial fins. Minimum diameter of the central core is fixed and the parameters to be explored are the number of fins, their thickness, length (radial dimension) and height. Although not included in the numerical simulations, the thermal resistance due to the use of a thin thermal interface material (TIM) layer between the LED lamp back and the heat sink is taken into account in the analysis. The main objective of the heat sink is to cool the LED lamp so that the lamp maximum temperature at the contact region with the heat sink is maintained below the critical temperature given by the manufacturer. This is a crucial aspect in what concerns the expected lifetime of the LED lamp and should be achieved at the expenses of as low as possible aluminum mass. Taking these criteria in mind, a design procedure is proposed and followed in the search for the improved heat sink to cool a particular LED lamp. Results obtained with the commercial code ANSYS-CFX clearly show the relative importance of the different governing parameters on the heat sink performance and allow the choice of the better solution within the frame of dimensional constrains. Although the present results concern a particular LED lamp, the proposed methodology can be extended to other types of heat sinks for general light and/or electronic components.

1. Introduction

In the past few years, LED lamps have been assuming a large role in the illumination market, mainly due to their potential in creating not only light but interesting light environments, associated with low power consumption even when compared with other *energy-saving* lamp types. Still, from the energetic viewpoint, LED lamps have not yet the desirable efficiency, as a considerable amount of energy is released as heat. This tends to increase the temperature of the LED lamps, leading to a decrease of their lifetime. In order to meet the expected long lifetime, LED lamps must operate below a certain temperature threshold, as given by the manufacturer. To ensure this, the heat sink associated to the LED lamps must provide the needed cooling, requiring the minimum mass of the involved material to obtain the heat sink. Additionally, internal electronic circuitry may have to be activated by cutting the electrical energy to the LED lamp, changing the illumination characteristics, if by any reason some overshoot on the temperature of the LED lamp occurs.

Thus, one may realize that the design of heat sinks used to cool LED lamps is of major importance to ensure their long lifetime. Heat sinks design criteria should contemplate not only their thermal performance, but also the associated manufacturing costs, which are directly related to the total material mass and production processes involved. For the latest criterion, a uniform cross section is

* Corresponding author.
E-mail address: v.costa@ua.pt (V.A.F. Costa).

http://dx.doi.org/10.1016/j.applthermaleng.2014.04.068
1359-4311/

Nomenclature

c_P	constant pressure specific heat [J/(kg °C)]
g	gravitational acceleration [m/s^2]
H	fin height [m]
H_c	height of calculation domain [m]
i	number of project variable [−]
k	thermal conductivity [W/(m °C)]
L	fin length, including central core [m]
L_c	radius of calculation domain [m]
M	heat sink mass [kg]
n	number of fins [−]
p	pressure [Pa]
Pr	Prandtl number [−]
$\dot{Q}$	heat flow [W]
r	central core radius [m]
R	Thermal resistance [°C/W]
Ra	Rayleigh number [−]
t	fin thickness [m]
T	temperature [°C]
u, v, w	Cartesian velocity components [m/s]
x, y, z	Cartesian coordinates [m]
X_i	Generic project variable

Greek symbols

α	thermal diffusivity [m^2/s]
β	volumetric expansion coefficient [1/K]
Δ	difference value
δ	thickness of the TIM layer [m]
θ	slice angle for calculation domain [rad]
ρ	density [kg/m^3]
μ	dynamic viscosity [kg/(m s)]
ν	kinematic viscosity [m^2/s]

Subscripts

c	core
i	optimization variable index
r	reference
s	solid
∞	ambient

desirable as it can be obtained from simple bars obtained by extrusion, followed by a cutting operation.

Heat sinks for LED lamps can operate under natural or forced convection, the first being the preferred ones as neither additional fans nor electric consumption are required. Additionally, noise generation by electric motors and fans is also avoided if natural convection heat sinks are adopted. On the other hand, natural convection heat sinks are thermally less effective, being consequently less compact and heavier, and need a careful design to reach the required thermal performance.

Heat sinks and LED lamps are assembled together using a thin layer of TIM, which, although designed to have a high thermal conductivity, locally increases the thermal resistance of the assembly.

Some studies can be found in the literature concerning the cooling of LED lamps. This can include what happens inside [1,2] or outside the LED module using detailed CFD studies in a steady-state approach, such as in Refs. [3–12], some of them including the packing aspects leading to the LED module. More specifically, Luo et al. [1] conducted a numerical and experimental study considering the whole set composed by the vapour chamber and a finned heat sink, and Arika et al. [2] consider the thermal management of the set composed by an assembly of LED lamps and a finned heat sink. In the work by Ying et al. [3], the optimization of the heat sink associated to a high power LED spot lamp is numerically studied. Scheepers and Visser [4] studied the heat management of high power LEDS using heat sinks through a numerical approach, and comparison is made between the detailed thermal model and simpler thermal resistance models. In the work by Christensen and Graham [5], a 3D numerical simulation is presented for an array of high power LED lamps together with a heat sink, and the thermal resistance network is analysed trying to estimate the different contributions for the heat management, in the search of compact LED systems. Chi et al. [6] performed the thermal analysis of high power LED lamps and the associated heat sink, using a CFD numerical simulation together with some heat transfer correlations, including radiation heat transfer. By its own turn, in the study by Weng [7] it is shown how a detailed 3D CFD analysis can improve the thermal performance of LED illumination systems. The study by Yu et al. [8] deals with the numerical simulation and optimization of a radial heat sink, with two alternative configurations having a void central part, for LED cooling purposes, concluding that it is impossible to optimize both thermal performance and heat sink mass, the work by Yu et al. [9] including also some experimental results for a similar heat sink configuration. Huang et al. [10] studied the thermal dynamics of the overall set of a LED fixture including the luminaire, the LED lamps and the heat sink, and Houl et al. [13] studied the thermal dynamics of a LED array system with in line pin fin heat sink. Ha [11] considered the numerical simulation of a high power LED package and extracted the values of the most relevant thermal resistances of the system. Yu et al. [12] analysed the effect of radiation heat transfer on the thermal performance of radial heat sinks similar to that considered in Refs. [8,9]. Studies considering the problem as a simple thermal resistance combination can also be found [14,15]. Some other studies also include the set composed by the LED module, the heat sink and the luminaries, like in Ref. [16]. The recent study by Yu et al. [12] shows how radiation heat transfer is relevant when analysing the thermal behaviour of this kind of heat sinks. Agostini et al. [16] present a detailed state of the art for high heat flux cooling technologies. In the work by Shyu et al. [17], a 270 × 1W LED array together with a plate fin heat sink in an acrylic housing is experimentally studied. The complete CFD numerical simulation of single-phase active liquid cooling systems, including minichannels for liquid circulation, can be found in Ref. [18]. Huang et al. [19] very recently proposed a constant power driving control for a 150 W LED luminaire, thus stabilizing the illumination of LED under large temperature variations.

However, in spite of the referred studies, no work was found concerning the heat sinks for the recent 4th generation LED lamps, like the FORTIMO lamps produced by Philips, more specifically when using a radial heat sink with a central core, obtained by simple extrusion and cutting manufacturing processes. Even if the heat sink by itself is not an energy saving device, it is crucial for the right operation during the expected long lifetime of the energy saving devices that are the LED lamps, and is a relevant applied thermal engineering problem.

The main objective of the present work is to find the improved geometrical configuration for an aluminum heat sink to be used in 4th generation FORTIMO LED lamps, given the heat release rate, critical (maximum) temperature of the LED module and space constraints. The improved configuration is, in the present context,