International Communications in Heat and Mass Transfer 72 (2016) 84–89

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Quantification of the natural convective heat transfer for the tilted and wire-bonded QFN32b-PCB electronic assembly☆

A. Baïri

University of Paris, LTIE-GTE EA 4415, 50, rue de Sèvres, F-92410 Ville d'Avray, France

ARTICLE INFO

Available online 1 February 2016

Keywords:
Natural convection
Thermal control
Electronics
Wire-bonding technique
Quad flat non-lead
QFN32b
Packaging
Convective heat transfer coefficient
Engineering applications

ABSTRACT

The version of the basic Quad flat non-lead QFN32 electronic device equipped with wire bondings, denoted as QFN32b, is more efficient thermally. This is due in part to the modification of the heat transfer phenomena occurring in the assembly. Although this interesting device is widely used in electronics, there are no specific correlations leading to determine accurately its associated natural convective heat transfer coefficient. This is the main objective of the present study, which considers a QFN32b generating a power ranging from 0.1 W to 1.0 W by steps of 0.05 W. It is welded in various positions of a printed circuit board (PCB), which could be inclined at different angles varying between 0° and 90° corresponding to the horizontal and vertical positions, respectively, by steps of 15°. These power and inclination angle ranges correspond to the normal operation of the device for the intended application. Calculations done by means of the finite volume method allow the determination of the free convective heat transfer coefficient on the different areas constituting the considered package. The results of the present study, compared with those of the basic QFN32 device quantified in a previous work, clearly show the influence of the wire-bonding technique on the QFN32b's thermal performance. The proposed correlations improve the design of this electronic device widely used in electronics for various applications covering many engineering fields.

1. Introduction

Electronics engineering is particularly concerned by thermal regulation. Technological solutions must be implemented to achieve the thermal conditions for the correct operation of the electronic devices in accordance with the manufacturers' recommendations. Natural convection is favored in engineering applications given its well-known advantages. This phenomenon avoids using external mechanisms such as fans, thus allowing to circumvent various problems, including risk of failure, energy consumption of the mechanisms during operation, and especially their acoustic and electromagnetic pollution. The size of the boxes containing the electronic assemblies is therefore limited. Several studies [1–7] deal with natural convection in confined environment for various geometries, including rectangular, cylindrical, hemispherical, triangular, and parallelogrammic shapes. The enhancement of the natural convective heat transfer by means of nanofluids is presented in refs. [8,9], while some techniques concerning the applied electronics are available in refs. [10,11]. The well-known Quad flat non-lead (QFN) device is increasingly used in electronics for many applications. Its thermal control is essential to ensure its correct operation, and its design must take into account all the assembly's technical characteristics. Control of the average and maximum operating temperatures is particularly important to ensure the reliability of the assembly during operation under the most adverse conditions. Exceeding the maximum temperature recommended by the manufacturer can lead to malfunction, performance decrease, and even shutdown and destruction. The strong and increasing integration of the electronic devices as the QFNs leads to volumetric heat flux of several GW·m^{-3}, associated with exchange surfaces increasingly reduced, which highly complicate their thermoregulation. The advantages of the QFN package can be consulted in many documents [12–17]. The convective phenomena concerning the basic QFN32 package have been addressed in recent surveys. This device is welded in many positions on the PCB and generates a power ranging between 0.1 W and 0.8 W. The board is inclined at different angles varying between 0° and 90°, corresponding to the horizontal and vertical positions, respectively. Correlations allowing calculation of the overall convective heat transfer coefficient and details concerning every area of the assembly have been proposed in [18,19].

The present survey considers the same conventional assembly in which the active device is a QFN32 equipped with 32 independent wire bondings. This device is denoted QFN32b. The wire-bonding technique implemented in various assemblies is widely described in the specialized literature. It consists in connecting the heat source of the QFN package to its leads by means of wires constituted by high thermal conductivity materials, generally gold, aluminum, copper, silver, and nickel. This interesting technique allows lowering the junction's average temperature, which increases the component reliability and allows

---

☆ Communicated by W.J. Minkowycz.
E-mail addresses: abairi@u-paris10.fr, bairi.a@gmail.com.

http://dx.doi.org/10.1016/j.icheatmasstransfer.2016.01.011
0735-1933/

Nomenclature

A	area (m^2)
g	gravity acceleration ($m\,s^{-2}$)
h	local convective heat transfer coefficient ($Wm^{-2}\,K^{-1}$)
$\overline{h}$	average convective heat transfer coefficient ($Wm^{-2}\,K^{-1}$)
$\overline{h_i}$	average convective heat transfer coefficient for a given i area ($Wm^{-2}\,K^{-1}$)
$\overline{h'}$	average convective heat transfer coefficient for the basic QFN32 ($Wm^{-2}\,K^{-1}$)
$\overline{h^*}$	ratio $\overline{h^*}=\overline{h'}/\overline{h}$ (−)
$k(\alpha), n(\alpha)$	coefficients of the $\overline{h}=k(\alpha)P^{n(\alpha)}$ correlations
$\overline{n}$	average $n(\alpha)$ value
P	generated power (W)
P_i	convective power exchanged by a given i area (W)
P^*	power ratio defined by $P^*=P_i/P$ (−)
T	temperature (K)
$\overline{T_i}$	average temperature of a given i area (K)
$T_{\max}$	maximal temperature (K)
T_c	temperature of the cavity's walls; initial temperature of the whole system (K)

Greek symbols

α	inclination angle of the PCB with respect to the horizontal (°)
δ	$\overline{h}$ deviation between exact values and those from correlations (%)
θ	dimensionless temperature $\theta=(T-T_c)/(T_{\max}-T_c)$ (-)

increasing the power generated by the QFN in the same initial volume. The enhancement of this package is due in part to the modification of the heat transfer phenomena, especially convection. Although this interesting device is widely used in electronics, to the knowledge of the author, there are no correlations to determine with precision the natural convective heat transfer coefficient concerning its different areas. In many engineering applications, this coefficient is often estimated by means of conventional Nusselt–Rayleigh type correlations concerning horizontal, vertical, or inclined flat plate under Dirichlet or Neumann thermal conditions. The precise determination of the average convective heat transfer coefficient is the main objective of this study considering a QFN32b, which generates a power ranging from 0.1 W to 1.0 W by steps of 0.05 W. It is welded in various positions of a PCB inclined at angles varying between 0° and 90° by steps of 15°. These power and inclination angle ranges correspond to the normal operation of the device for the intended application. The results obtained by means of a numerical approach using the finite volume method clearly show the influence of the wire-bonding technique on the electronic package thermal performance. The correlations proposed in this survey allow the determination of the free convective heat transfer coefficient on the 3 areas of the QFN32b, according to the generated power and the PCB angle inclination.

2. The treated assembly: calculation method

The treated electronic assembly represented in Fig. 1(a) is constituted by a basic square PCB (100 mm side, 1.6 mm thick) on which the QFN32b package is welded. The board could be inclined with respect to the horizontal plane by an angle α varying between 0° and 90° by steps of 15° (Fig. 1(b)). The PCB's thermal conductivity being anisotropic, its equivalent values are assumed to be equal to 20 $Wm^{-1}\,K^{-1}$ in the board's plane and 0.35 $Wm^{-1}\,K^{-1}$ in its thickness. The QFN32b detailed in Fig. 1(c) could be installed in any position of the PCB. The basic model of this package named QFN32 is presented in many documents and in [18,19]. In summary, the surface layer (1) (20 μm thickness) of the die (2) constitutes the device's active part. It generates during operation a power P ranging from 0.1 W to 1.0 W. It is fixed to the diepad (3) located at the bottom by means of a thin paste layer (4). The 32 leads (5) connect the package to the PCB, and the whole device is encapsulated by means of a molding compound (6). From outside, the package is a parallelepiped (square of 5 mm side and 0.9 mm thick) represented in the Fig. 1(d). The particularity of the wire-bonded version named here QFN32b is that the surface source is connected to the 32 leads by means of high thermal conductivity wires (7) of 25 μm diameter (Fig. 1(c)). They are regularly distributed on the source face in order to homogenize as much as possible its temperature during operation in the whole P range. Thermoregulation of the assembly is based on the maximal value of this junction temperature, which must be controlled in order not to exceed the maximal value for the most unfavorable thermal and geometric conditions. The isotropic thermal conductivities of the device's materials are the same as in [19]: 120, 260, 260, 2.1, and 0.66 $Wm^{-1}\,K^{-1}$ for the die, the diepad, the leads, the paste, and the molding compound, respectively. That of the wires is set to 300 $Wm^{-1}\,K^{-1}$, corresponding to the average value of the main material associations used in this technique. All the thermal conductivities are considered as constant and temperature independent. The assembly is subjected to the natural convective phenomena being installed in a large air-filled cubic cavity (600 mm side) to avoid the boundary effects and to ensure that the natural convective flow is unobstructed. Air inside the cavity is isothermal at $T_c=293.15$K. The considered α and P ranges as well as the position of the device on the PCB correspond to the real operation of the electronic assembly, which is decomposed into distinct areas:

(i) the top face, the sides, and the back face of the QFN32b, denoted as (Q_T), (Q_S), and (Q_B), respectively, in Fig. 1(a);
(ii) the top face (except the (Q_B)'s mark), the sides, and the back face of the PCB, denoted as (B_T), (B_S), and (B_B), respectively, in Fig. 1(d).

The adopted calculation method is detailed in ref. [19] so only the main data are summarized here. The conventional continuity, momentum, and energy system is solved by means of the well-known control volume method, associated with the SIMPLE algorithm. The mesh is nevertheless different for the QFN32b. The wire bondings' shape, length, section, and contact with the leads require a significant preliminary work. Refinements are done:

(i) at the wire–lead interfaces to examine precisely the conductive heat transfer, which constitute the main difference with the basic model QFN32;
(ii) around these interfaces and in the contact between the environment and the 5 assembly's areas (Q_T), (Q_S), (B_B), (B_S), and (B_T).

This operation allows the determination of the thermal gradients distribution of the m wall elements $(\partial T_j/\partial n)_{j=1-m}$. These data are essential to know the convective exchanges, the main objective of this study. The optimized version of the mesh used for all the treated combinations (α and P) is constituted by 2,012,429 nodes. It is of about 5.6 times denser than that adopted in [19] for the assembly equipped with the basic QFN32 (358,955 nodes). Calculations based on the same convergence criteria (10^{-5} for the velocity components and 10^{-6} for the energy) are done by means of the Ansys-Fluent software [20] confirmed in some cases by a house code. A second house software is developed to determine the parameters quantifying the convective heat transfer characteristics. The distribution of the local convective heat transfer coefficient $h_i=[-\lambda(\partial T_i/\partial n)/(T_i-T_c)]_{i=1-m}$ allows the determination of the average convective heat transfer coefficient $\overline{h}$ corresponding to the (Q_T), (Q_S), (B_B), (B_S), and (B_T) areas. This is obtained with by ponderation of the local values over their corresponding