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Thermal Management Process in Automotive Exterior Lighting Products

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Abstract

In this study, the thermal management process in the design phase investigated for automotive headlamp and LED (Light Emitting Diode) light module. Thermal management has importance for long lifetime and material selection. Halogen light source leads to warm in the design space as between 5-10 percent of power is only transferred into visible light and the rest converts into heat. While the energy of LEDs transfer at least 20 percent into visible light and the rest of the energy generates heat within electronic components and spreads over PCB (Printed Circuit Board). Nevertheless, the heat dissipation on PCB should be controlled because LEDs have junction temperature (T-junction), which is critical for luminous flux degradation and cooling system. Hence, thermal management of LED light module for automotive headlamp investigated with numerical experimentation and results compared with tests which have a good correlation with each other. Numerical experiments performed in headlamp is investigated in terms of temperature distribution. Also, the halogen light source was considered within the same design space and temperature distribution was presented with numerical experimentation and results compared with tests. In numerical experimentation, it is important to predict close results for both LED and halogen light sources in the design phase as both relate to performance of lighting product. While halogen light source directly affects the plastic materials, considered in the design, LEDs result in degradation of luminous flux and have effect on PCB materials. Plastic materials' thermal performance is defined with Vicat softening temperature. Well-correlated numerical experimentation with tests is achieved by utilizing FloEFD thermal simulation software.

Keywords: CFD (Computational Fluid Dynamics) in Automotive Lighting, Headlamp, Luminous Flux Degradation, Thermal Management of Lighting Products, Junction Temperature of LED's

INTRODUCTION

Revolutionary technological developments are more seen in the automotive and also in the headlamps. Automotive lighting has gain importance year to year. Although, lighting parts are one of the most attractive stylistic components of automotive, it has crucial functions on safety requirements. Nowadays, Light Emitting diodes (LED) are used commonly instead of halogen lamps. The first fully LED headlamp was introduced in 2008 [1]. The significant advantages of the LEDs are high efficiency, longer lifetime, material cost reduction, response time and unique stylistic concepts [2]. In near future, pixel lighting will also be on the roads besides the other several automotive technologies [3].

One of challenges for the automotive exterior lighting systems design is to predict thermal limits. Different light sources have different effect in thermal distribution for headlamp and its components. Halogen light source heats design space with over %90 percent of energy transferred into heat, however LEDs heat printed circuit boards (PCB) rather than entire headlamp. Thus, all the damages, cause by LEDs' heat generated, affects life time, luminous flux degradation, and PCB. Hence, heat is generated besides visible light and removed away from source by three ways: conduction, convection and radiation. Conduction is important to spread out the heat on the surface area, therefore PCBs have copper layers, which present over FR4 material, and thermal vias. Although, the packages getting smaller to reduce design space, this requires better conduction with the same surface area as power dissipation kept same. Convection moves away from the surface into the air and the temperature rise and also required surface area can be calculated with a suitable heat transfer coefficient, advisably it is taken 1.2 mW/(cm2-°C) without air flow [4]. Between the surfaces, heat transfer occurs with thermal radiation. However, it is commonly ignored when LED is used as light source.

Technological developments and stylistic aspects drive companies to build up LED based designs with the small packages and modules. LED module has to ensure the regulated light pattern for safety while, it also must satisfy customer demands in lighting performance. In this study LED module is considered in terms of thermal characteristics.

Thermal Design

The thermal design in automotive exterior lighting products affects reliability. Thermal management process, which include pre-design for quotation and validation tests before the serial production, is long term work. Several tests and analyses are performed at all design stages. Thermal expectation from design criteria is to make appropriate selection of material which has effects on cost, manufacturability and lifetime. Spread of the heat dissipations on the PCBs is another critic thermal expectation. Many electronic lay-out options are tried to get the optimum.

The process starts with determining thermal powers on each component, and making initial calculations for the PCBs' dimensions. Initial power estimations are defined through the electronic and the optic requests. Options of thermal management will put forward the cooling strategy. Passive cooling on the PCBs is directly related with surface area, after determining the power of components. If the allocated lighting space does not dissipate heat generated to keep the components safe enough, active cooling systems are considered.

Thermal criteria differ case to case with technology utilized in lighting. Halogen or LEDs, the light source defines the requirements from the thermal management. Even though, the plastic parts get more warmed with halogens, Vicat softening temperatures of the plastics are controlled for both. Headlamp and rear combination lamps have different responsibilities to perform. Each responsibility is called functions of lighting product considered. If headlamp and module is considered, functions are Low Beam, High Beam, Signal and Cornering. If LED is the light source, extra numerical experiments run to predict luminous flux degradation, which is caused by junction temperature of LEDs, on each functions. The degradation is important because of optical necessity to satisfy the regulated light pattern.

In design phase, thermal simulations and the prototype tests are the main tools in decision making. In numerical experimentations, fluid and thermal simulations provide high accuracy results and, also give the chance to try-out various options to construct optimum design before the prototype tests installed and production facilities started [5].

NUMERICAL MODEL AND METHOD

Methodology in numerical experimentation starts with model meshing step and the predefining experimental step before finishes with solution step. In numerical experimentation, it is important to obtain a good quality mesh. Hence, simplifications to design geometry can be applied before meshing process in order to increase the quality.

Steady-state laminar and turbulent natural convection, conduction and, radiation heat transfers were considered for all the fluid and thermal analyses. Internal natural convection occurs when a density variation exists in a gravitational field. The incompressible ideal gas law is applied in density calculation. The fluid density and, therefore velocity variations depend on the input ambient pressure and the computed fluid temperature.

The Navier-Stokes equations, which are formulations of mass, momentum and energy conservation laws, are solved in solution step. The conservation equations in the Cartesian coordinate system can be written as follows [6]:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho u_i) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial p}{\partial x_i} = \frac{\partial \tau_{ij}}{\partial x_j} + S_i^{gravity} \tag{2}$$

$$\frac{\partial}{\partial t}(\rho H) + \frac{\partial}{\partial x_i}(\rho H u_i) = \frac{\partial}{\partial x_j}(\tau_{ij} u_j + q_i) + \frac{\partial p}{\partial t} + \rho\varepsilon - \rho g_i u_i + Q_H \tag{3}$$

$$H = h + \frac{u^2}{2} + \frac{5}{3}k$$

Here, u_i is the flow velocity, p is the static pressure, ρ is the fluid density, S_i is a mass-distributed external force per unit mass due to buoyancy (where g_i is gravitational acceleration), h is the thermal enthalpy, k is kinetic energy of turbulence, Q_H is a heat source or sink per unit volume, is the viscous stresses, q_i is the diffusive heat flux and is proportional to the temperature gradient.

Thermal modelling can be defined at several levels from 0 to 4 with increasing model details. The simulation model in FloEFD software differs by necessity of details. Although, halogen bulbs were constructed a thermal model with glass, legs and tungsten filament which defines level 2 modelling, semiconductors' packages and passive components were modelled as a brick with lumped conductivity which defines level 0. Volumetric heat generation rates were applied on the solid bodies. Monte-Carlo radiation model with 15,000,000 rays was used, because halogen bulbs approximately %83 percent of the input energy is lost as heat radiation. Radiative surfaces at walls are defined for aluminum-coats.

Constant thermophysical properties are specified at the average fluid temperatures. Transitional turbulence, k-ε model, which have capability to determine all flow regimes, was used in FloEFD [6].

Numerical model of the LED light module is shown in Fig. 1. Fluid, solid and partial cells were created in the domain. The partial cells are present at the fluid-solid interfaces. Number of the cells are given in Table 1.

Table 1 Number of cells

	Light Module	Headlamp
Cells	610k	4,710k
• Fluid cells	350k	2,640k
• Solid cells	260k	2,070k

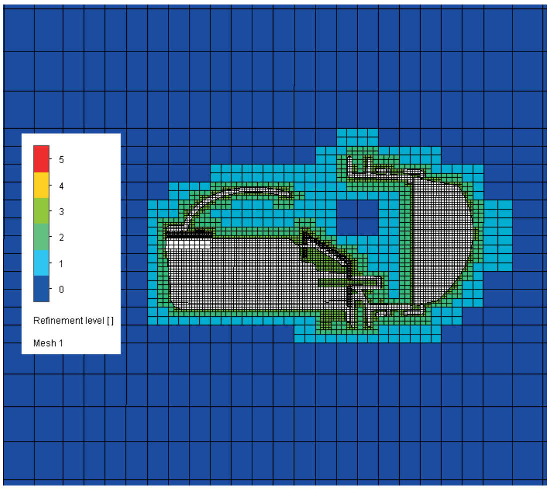

Figure 1 Structured Cartesian immersed-body mesh of the LED module

In LEDs as light source, predicting junction temperature is important to define lifetime. However, direct measurement of the junction temperature is unfavorable. Instead, estimated junction temperature is calculated based on the solder point temperature and LED's thermal resistance value, which is given 1.3 °C/W in the LED datasheet [7]. In the Eq. 4, R_{th} is the thermal resistance and P is the power supplied.

$$= T_{solder}[°C] + (P[W] \times R_{th}[°C/W]) \tag{4}$$

EXPERIMENTAL SET-UP AND RESULTS

Solder point temperatures can be measured by the sets of thermocouple. Before the measurements, hot spot temperature positions have to be determined. It is necessary to predict correct locations for thermocouples. Although, the correct locations can be predicted with the numerical experimentation, thermal camera can also be utilized. Preliminary design of LED light module is shown in Fig. 2.

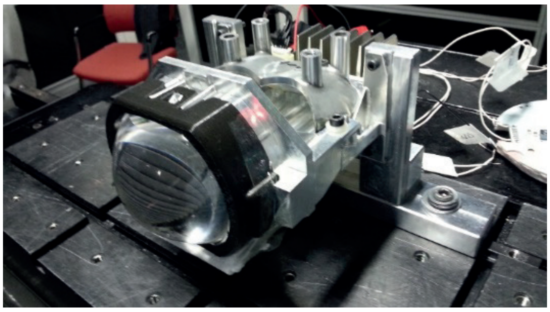

Figure 2 Preliminary design test product

Light Module Test

LED light module was tested in without air flow condition. It is convenient to make an open air measurement test to see whether electronic device work properly. Instantaneous infrared camera view, FLIR E60 type camera was used in measurement, is shown in Fig. 3.

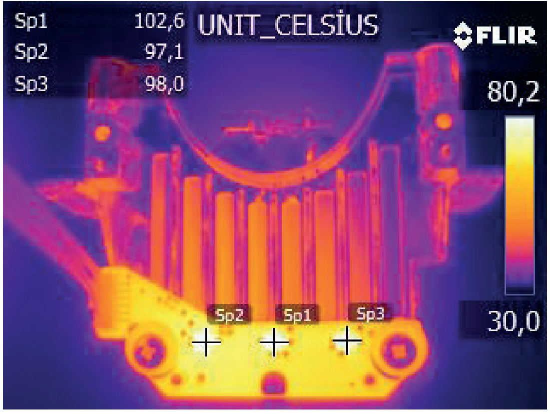

Figure 3 Thermograph picture of the light module

The center LED was chosen for the measurement and, the thermocouple installation was done as shows in Fig.4. Hence, it can be said that thermocouples' locations were determined correctly.

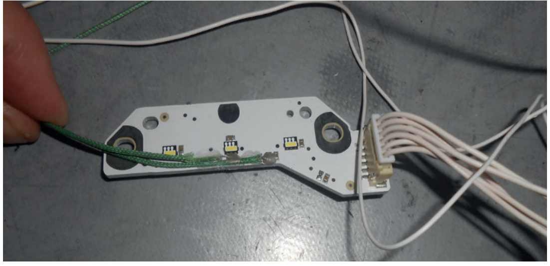

Figure 4 Thermocouple installation to low beam LED

Headlamp Test

Halogen or LED light module inside the headlamp is exposed to various tests. Two thermal validation tests are mainly requested for LEDs' before the design approval. First test scenario or maximum temperature (T_{max}) test scenario, in which all the functions light on, is common for the halogen and LED headlamps. This is built up to predict the limits in terms thermal requirements. First scenario consists Day Time Running Lamp (DRL), Low Beam (LB), High Beam (HB), Fog and Turn Indicator (TI) to be continuously light on at 28V, in 50°C ambient temperature.

T_{max} test result for LB LED is given in Fig. 5. The solder point temperature is measured 143°C and estimated junction temperature was calculated 149°C from Eq. 4.

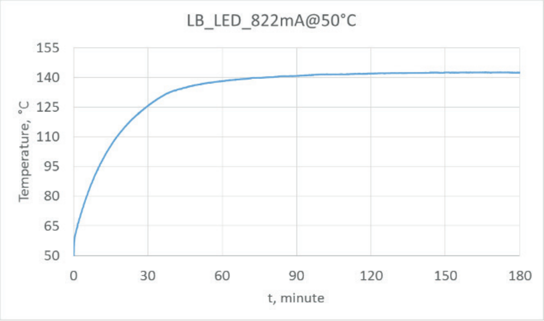

Figure 5 T_{max} test graph at 50°C ambient temperature

Numerical experimentation result was given in Fig. 6. Center LED solder point temperature is 137°C.

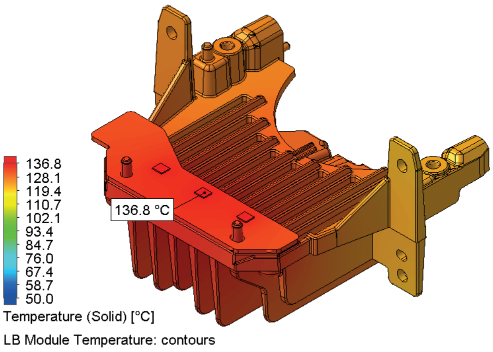

Figure 6 T_{max} simulation result at 50°C ambient temperature

Maximum temperature test is critical in predicting the thermal endurance of the lighting product. Junction temperature of LED type used in module is predicted to be 150°C by the manufacturer [7]. Junction temperature is important because lifetime of the LEDs depends on the junction temperature. Hence, any junction temperature exceeding the value predicted by manufacturer, LED lifetime will decrease dramatically [8, 9]. The center LED temperature was predicted through numerical experimentation and test.

Comparison of numerical and experimental results for LB LED light module in headlamp, were given in Table 2 in terms of solder point temperatures. Correlation between numerical experimentation and test are fairly good.

Table 2 Test and simulation results for low beam LED light module solder point temperature at 50°C and 23°C ambient temperatures

Low beam LED	Test	Simulation
$T_{-solder}$ @50°C	143°C	137°C
$T_{-solder}$ @23°C	87°C	85°C

Temperature distribution on plastic components is important because of Vicat softening temperature (VST). VST defines the ultimate temperature of plastic component can withstand. Numerical experimentation results are at critical importance in predicting temperature distribution in headlamp when the functions are active. If material's VST is lower than the maximum temperature, an alternative plastic material should be considered which has higher VST.

Temperature distributions of the halogen headlamp with all plastic parts was shown in Fig. 7, after T_{ma} numerical experimentation.

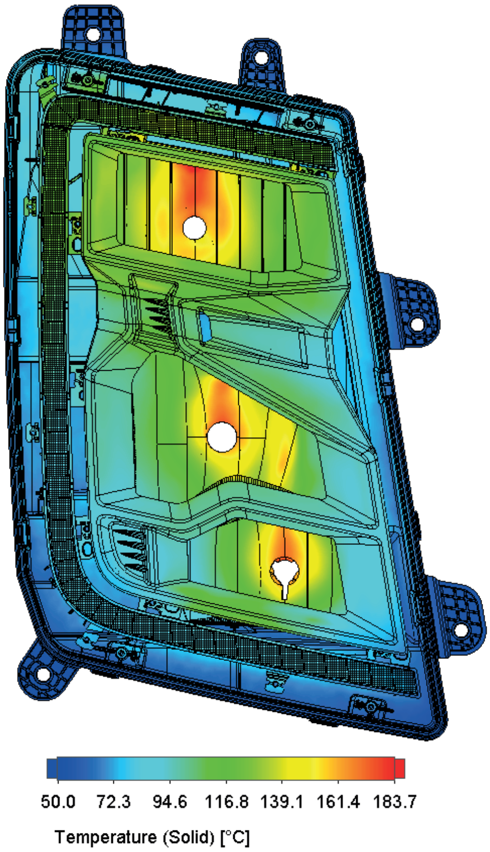

Figure 7 Halogen headlamp plastic parts temperature distribution at T_{max} simulation

After LB LED light module was replaced with H7 halogen bulb, headlamp plastic parts were measured at T_{max} test. Thus, worst case was investigated for the plastic parts. Difference between maximum temperature predictions from numerical experimentation and test is shown in Fig. 8.

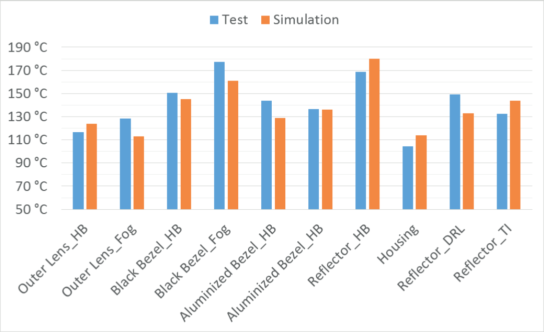

Figure 8 Halogen headlamp plastic parts temperature results comparison

Second test scenario that is regulated by ECE_R128-00 norm, is to check luminous flux degradation for LEDs [10]. Therefore, it was tested only for LB LED light module at 23°C ambient temperature. LEDs manufacturer supplies a relative luminous flux versus junctions' temperature graph. By utilizing the LED datasheets or photometer instruments, photometrical characteristics of the LEDs can be estimated or measured. In Fig. 9, numerical experimentation results for degradation was shown.

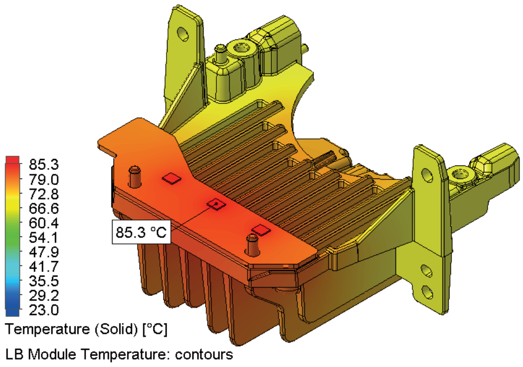

Figure 9 Degradation simulation result at 23°C

Degradation is being defined with junction temperature, so it is important to estimate junction of LEDs. Junction of LED was estimated 94°C and from the relative luminous flux versus $T_{junction}$ graph supplied by LED manufacturer, 10% degradation is estimated for LED module [7]. In Fig. 10, temperature increase with time from the degradation test result was shown.

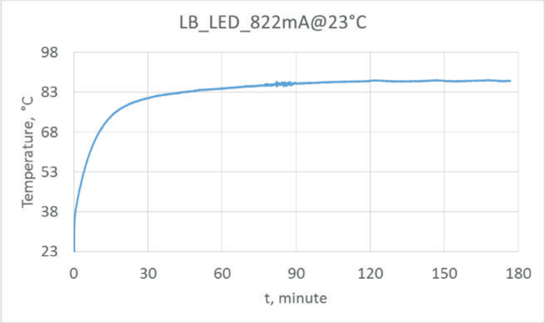

Figure 10 Degradation test graph at 23°C ambient

LB function of the headlamp was achieved for both halogen and LED light module options. Energy consumption of both light source was illustrated in Table 3. Higher luminous efficacy means power saving in low beam and

LED lighting is more efficacious than any other conventional lighting technologies [11].

Table 3 Energy consumption of halogen and LEDs for low beam function

H7 halogen bulb	75 W
LED light module	22 W

Low beam, is continuously on, is the main function of headlamp at night time driving. LED light module is an economical alternative of halogen bulb, because of nearly 71% power saving with LED light module can be achieved. Headlamp assembly with low beam LED light module was shown in Fig. 11.

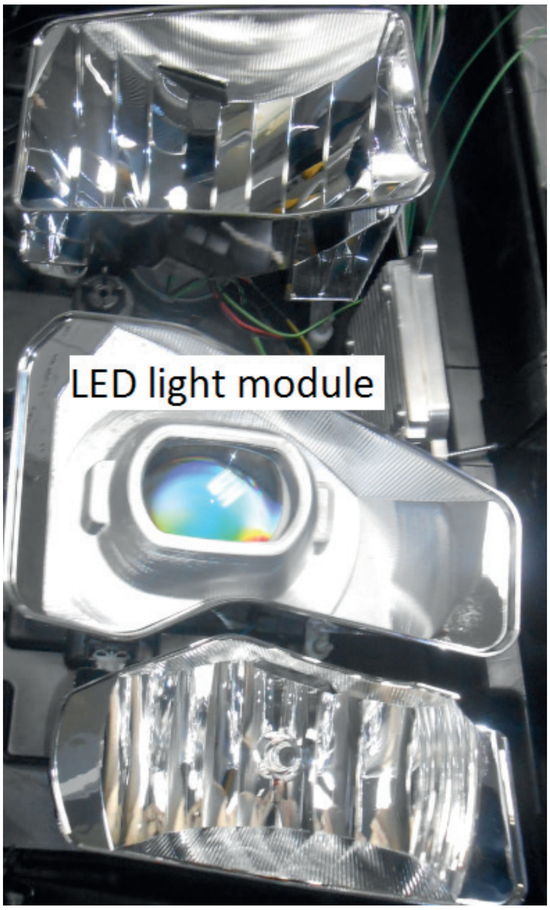

Figure 11 Light module inside the headlamp

CONCLUSION

Thermal management process of lighting products was illustrated with halogen bulb or LED light module, inside the headlamp assembly. Importance of accurately predicting the junction temperature of LED in thermal management process is addressed as predicting LED lifetime and luminous flux degradation for LED. Junction temperature of electronic components and maximum temperatures of the plastic parts must be kept under the limits. Vicat softening temperature gives the critical limits for plastic parts. If under estimated temperature distribution is present, then headlamp will be out of service, because of not satisfying its main function of lighting. Lifetime of LED and proper choice of plastic material are identified through fluid and thermal simulations before the product tests. The results of the study show that temperature of the lighting products can be estimated using with numerical experiment, is fit with test results.

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REFERENCES

[1] Hamm M., and Huhn W., (2008) SAE Technical Paper Series (2008-01-0337), Design claims and technical solution steps generating the world first full LED headlamp

[2] Ott H., and Nylander J., (2002) SAE Technical Paper Series (2002-01-0383), Ultra-thin automotive lamps (8-12mm) using special SMT LEDs and special optics.

[3] DrivingVisionNews.com, Vehicle lighting in Japan technics, Automakers, Tier1 and Tier2, (2018)

[4] Mauney C., Texas Instruments, Thermal considerations for surface mount layouts

[5] Kikuchi K., Hamashima Y., and Kobayashi Y., (2005), SAE Technical Paper Series (2005-01-0864), An approach to predicting LED junction temperatures with fluid and thermal analysis

[6] Mentor®, 2018, FloEFD for CATIA V5 technical reference, software version 17.

[7] Osram, OSLON® Black Flat, technical datasheet KW H3L531.TE, http://www.osram.com, 01 October 2018.

[8] Ansari A., Ince W., and Sayers M., (2007), SAE Technical Paper Series (2007-01-1037), Towards development of thermal standards for the design of LED lamps.

[9] Donahoe D. N., (2009) IEEE, Thermal aspects of LED automotive headlights

[10] UN Regulation No. 128 - Light Emitting Diode (LED) light sources, https://www.unece.org/fileadmin/DAM/trans/main/wp29/wp29regs/2015/R128e.pdf

[11] Pattison P. M., Hansen M., and Tsao J. Y., (2017), Comptes Rendus Physique 19 (2018) 134-135, LED lighting efficacy: Status and directions