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Thermal Analysis of Automotive Headlamp

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Abstract: *In this study, experimental analysis by using thermocouples and thermal imaging camera along with numerical analysis was performed to define thermal distribution inside the head lamp because of usage plastic materials and thermal loads. Buoyancy, radiation and conjugate effects were considered. Velocity and temperature distributions were obtained and possible hot spots can be determined. The present study carries out an experimental analysis on a automotive headlamp to determine the thermal characteristics and behaviour. Numerical analysis done through CFD technique is utilized to validate the experimental results. Thereby, showing simulation strategy using CFD methodology to determine the airflow and temperature distributions within a headlamp design. The methodology presents a fair agreement with the experimental and numerical analysis results*

Keywords: *Automotive headlamp, Thermocouples, Thermal Imaging Camera, hotspot, thermal degradation,*

I. Introduction

Modern automobile lamps have a complex body design and contain powerful built-in sources of light. This can create problems for the materials used for their construction. The complex geometry and the combination of radiation, thermal conduction and free convection make difficult to find areas of critical temperature distribution inside the headlamp. Thus headlights need to be extensively tested to avoid damage caused by high temperatures. Experimentation under the same conditions determines the accuracy of the results or detects possible errors.

1.1 Structure of Headlamp

The headlamp studied in this paper is sample type of headlamp which can be observed in Figure 1. The H4 type bulb has two filaments named high beam and low beam which are the main heat source inside the headlamp.

Fig-1: Front View of Headlamp

The main parts of the headlamp are lens, reflector, bulb and coating, out of which the coating is made from polycarbonate material. This sample headlamp has 3 vents for proper air distribution. Two of the vents are located at bottom and one at top, assuring the heated air to escape.

1.2 Heat sources inside the headlamp

The main heat source inside is the filament of bulb which gives heat in all three forms i.e. conduction, convection and radiation. Other sources like radiation from sun, atmosphere also contributes as heat source.

1.3 Thermal Imaging Camera

IR radiations are emitted by all the objects which are captured by the IR sensor of the camera. It is mostly used to find the surface temperature of a object. The thermal camera used here is of FLIR make E85 model which captures 76,600 pixels of thermal data. The accuracy of measurement is ± 2℃.

II. Mechanism Inside The Headlamp

The flow of air inside the headlamp depends mainly on natural convection which is forced by the heat from the light bulb. The light bulb will heat the surrounding air and force the hot air to rise as new colder air enters from below. Radiation from the sun and the light source will be reflected by the reflector and energy will be absorbed by the nearby surfaces and cause the adjacent air to be heated. The heat absorbed by the surfaces will be transported through the materials by heat conduction. The headlamp casing is equipped with three ventilation holes that allow the headlamp to breathe.

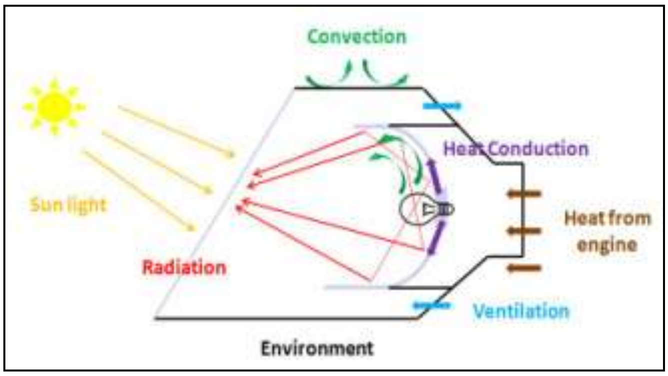

Fig-2: Mechanism inside the headlamp

The flow inside the headlamp is mainly depends on the natural convection phenomena. The tungsten filament emitting the heat that will heat the surrounding air inside the headlamp enclosure. Due to the phenomena of natural convection process the colder air enters from the bottom ventilation hole that will force the hot air rise to pass through the top ventilation hole [1]. Buoyancy force mechanism is the principle that has been done the above process. Both the natural convection and buoyancy force mechanism together to work with the inside the headlamp.

III. Experimental Setup

The setup contains Headlamp, SMPS, Thermocouples, Thermal imaging camera, Wattmeter and Data Acquisition System. The SMPS used in desktop CPU is modified by adding a capacitor to obtain the required power for the bulb to operate. This is done as the headlamp requires DC current. K-type thermocouples are used for measuring the surface temperatures. The thermocouples are pasted by using an adhesive tape. Thermocouple calibration is done to check the effect of adhesive on the temperature reading. The difference found is of 1% maximum. These K-type thermocouples are connected to the data acquisition system which records the temperature data for every one second. The wattmeter is connected so as to get the power consumed by the headlamp.Initially, the headlamp is kept in working conditions (Status ON) for about two hours. Considering the average speed of the vehicle as 40 km/hr, air is forced on the headlamp to get the actual real life conditions, where the air is forced on the headlamp due to the travel of the vehicle.The thermal camera is used for getting an overview of hotspot regions. Correspondingly, the thermocouples are pasted on the hotspot location.
Grid formation is done on the cover as shown in fig 3

Fig 3 Setup Of Experinment

Then the data acquisition records the data for about 5 minutes i.e. 300s. About 300 values of temperature are obtained for a single point, average of which is taken as final temperature at that point. The experiments are run for two different powers of 55 W and 100 W and the hotspot regions are found out.
Sets are created according to locations shown in the fig 3.
Set A contains 8 locations marked from 1-8. Similarly other sets are created.

IV. Results And Discussion

The results here are for both the cases. The first case has the bulb of 55 Watts and second is of 100 Watts. The images obtained from the thermal imaging camera and temperatures from thermocouples are also discussed.

4.1 IR thermograph

Fig 4 Temp At Source Using Thermal Imaging Camera

Fig 4 shows the clearly indicating the hotspots and the maximum temperatures for bulb of 35W. The maximum temperature to which the headlamp is heated is 102 ℃.

4.2 Using thermocouples

Among the five sets two sets are shown in gragh which states the temperatures at that location which have the maximum temperatures for bulb of 35 W

Chart -1: Temperature distribution along the location for 35W.

Chart -2: Temperature distribution along the location for 35W

From the physical grid generation figure 3, the SET B includes the location from 9-15 and the maximum temperature obtained from the set A is at point number 13. The highest temperature from set B is 53.42℃ which is shown in Chart -1. Similarly from Chart -2 the SET A ranges from point number 1-8 and the highest temperature is at point 8 which is 49.13℃

4.3 Using CFD Analysis

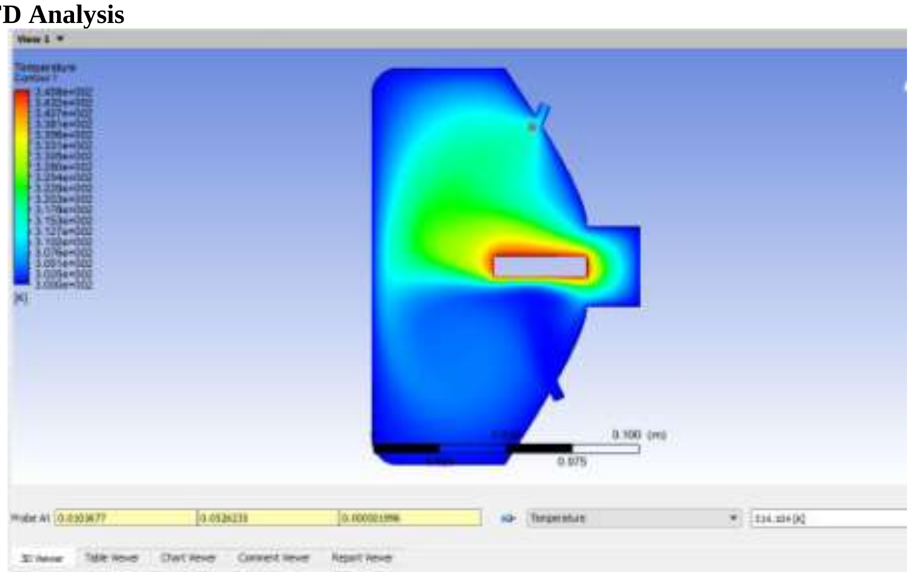

Fig 5 Temp At Exit Vent At Velocity= 0.1m/s

By providing the vent for natural convection inside the headlamp great heat flow out of the inside volume can be obtained. Above simulation shows the vent position on top and bottom side provides natural convection to carry the heat from source to surrounding .This phenomenon reduces the temp increase in the lamp body and degradation of glass material. Thus the danger of yellowish film formation on glass surface can be minimized.

V. Conclusions

- As the experiments are conducted for two different wattages of the bulb and the numerical analysis is done for the same. From this we can conclude that for 12/35 W the maximum temperature is 53.42 deg centigrade and it is in an acceptable but exposure to long running time create temperature rise to high level.
- Similarly from the reports of thermal imaging camera as mentioned in above section, we can conclude that the maximum temperature region is at the upper side of the headlamp which is same as that of experimental readings. So for finding out the surface temperature thermal imaging camera is the best device. Also it is very easy to handle.
- Similarly CFD simulations on the model have shown a fair agreement with the experimental work. The innovative techniques like CFD can thus be used to predict the thermal behaviour and air flow pattern within complicated headlamp structures before the actual prototype is being manufactured. Thereby, the CFD technique provides a cost effective and thermally optimized headlamp model to the market.

Future Scope

- Although the bulb with 12/35W gives the maximum temperature that is fairly acceptable, the thermal degradation at that point will occur continuously. In case of heavy vehicles where the running time of the vehicle exceeds 12hr per day the hotspot are not acceptable.
- The vents provided on headlamp in cfd simulation can be brought in use by proper designing of diameter around 5mm.
- Vent opening may require filtering element if the operating environment is dusty .In this case suitable fabric filter of few micron size should be use.

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