© Strojniški vestnik 50(2004)2,72-79
ISSN 0039-2480
UDK 536.5:628.94
Izvirni znanstveni članek (1.01)
© Journal of Mechanical Engineering 50(2004)2,72-79
ISSN 0039-2480
UDC 536.5:628.94
Original scientific paper (1.01)

Eksperimentalno določanje temperaturnega polja površine žarometa z uporabo uporovnih zaznaval

Measurement of the Surface-Temperature Field in a Fog Lamp Using Resistance-Based Temperature Detectors

Andrej Wagner - Ivan Bajsić - Matija Fajdiga

Sodobni žarometi so večinoma izdelani iz plastičnih mas, ki so sicer zelo primerne za izdelavo zahtevnih oblik, vendar so navadno temperaturno slabo obstojne. Posledice temperaturnih obremenitev so deformacije, ki imajo lahko vpliv na fotometrične lastnosti ter na odpornost žarometa na zunanje vplive.

V pričujočem prispevku smo za določen primer žarometa določili temperaturno polje na notranji in zunanji površini okrova žarometa ter temperaturo na delu parabole in senčniku. Merjenje temperatur je bilo izvedeno z uporabo uporovnih zaznaval iz platine. Rezultati meritve so omogočili določitev trirazsežnega temperaturnega polja okrova žarometa.

(Ključne besede: žarometi avtomobilski, polja temperaturna, meritve temperature, metode eksperimentalne)

Modern headlamps are made from low-cost plastic materials that are very convenient for the design of these products. However, plastic materials are not suitable for use at high temperatures. The result can be deformations that result in problems with the photometric properties and with the sealing of the headlamp.

In order to predict the deformations the temperature was measured at significant points on the outer and inner parts of the headlamp housing, on the reflector and on the shield of the lamp. The measurements were made with a platinum-resistance temperature detector (RTD). The results of the measurements were then used in a finite element method (FEM) analysis to determine the deformations of the headlamp housing.

(Keywords: vehicle headlamps, temperature fields, temperature measurements, experimental methods)

0 UVOD

Merjenje temperature na površini je zelo zahteven postopek, ker težko določimo pravi stik med zaznavalom in površino merjenca.

Za pregled porazdelitve temperature je zelo primerna toplotna kamera. Ta da trirazsežno porazdelitev temperature po žarometu, njena pomanjkljivost pa je, da je za določitev natančnih vrednosti potrebno dobro poznavanje emisijskih lastnosti površine merjenca. Podatki za emisijske lastnosti so zelo pomanjkljivi oziroma nedostopni.

Naša naloga je bila določiti temperaturo na delih žarometa, ki so se s prejšnjimi meritvami s pomočjo brezdotikalnega infrardečega inštrumenta za merjenje temperature pokazale kot kritične, ali pa so bile pomembne kot robni pogoji za kasnejšo

0 INTRODUCTION

Measuring the temperature of a surface is a demanding process, because it is very hard to determine the actual contact between the sensor and the surface being measured.

The thermal camera can give a very good overview of a temperature field. The camera also gives a good threedimensional view of temperature, but it also has a few drawbacks. If the emissive values of the surface are not known, the true value of the surface temperature cannot be determined, and the data for surface emissive values are often hard to get or are simply not available.

The aim of this work was to determine the temperatures on specific points of a lamp housing. The temperatures were determined with infrared measuring equipment and a thermal camera. The results from the measured points were taken as input data for subsequent analizo z uporabo metode končnih elementov (MKE). Meritve s toplotno kamero in infrardečim termometrom so tudi pokazale, da je porazdelitev temperaturnega polja po različnih modelih meglenke podobna. Temperatura se po višini zmanjšuje linearno, prav tako se zmanjšuje linearno v globino žarometa. Pokaže se tudi skok temperature v točki nad žarnico.

V preteklosti je bil za merjenje temperature večinoma uporabljan termočlen, katerega največja pomanjkljivost je bila nezmožnost postavitve zaznavala na površino.

Z izmerjenimi vrednostmi smo kasneje določili približno funkcijo porazdelitve temperature. Določitev natančne temperature površin ter njena porazdelitev sta zelo pomembni za analize toplotnih obremenitev okrova ([5] in [6]). Zaradi statistične analize rezultatov smo avtomatizirali zbiranje in shranjevanje podatkov.

Rezultati meritev in postopek določitve temperaturnega polja bodo omogočali kasnejši preračun meglenk z manjšim številom meritev, oziroma bo pri začetnih različicah meglenke omogočal toplotno-mehanski preračun brez meritev na žarometu. Tak način omogoča hitrejši in cenejši razvoj izdelka ter odpravljanje napak, povezanih s toplotno obremenitvijo v zgodnjih fazah razvoja. Tak postopek je skladen s postopkom zagotovljivosti.

Postopek določanja temperaturnega polja bo predstavljen na primeru meglenke podjetja Saturnus avtooprema d.d.

1 PRIPRAVA MERITVE

V okviru raziskave smo izdelali zasnovo merilne verige, izdelali program za zbiranje in shranjevanje podatkov, celoten sistem smo umerili in na koncu smo izvedli meritev in rezultate statistično ovrednotili.

1.1 Zasnova merilne verige

Meritve smo izvajali z 10 uporovnimi temperaturnimi zaznavali Pt-1000 z linearno karakteristiko. Pri meritvi je bila uporabljena dvožilna merilna metoda, kar pomeni, da je bilo za zbiranje podatkov mogoče uporabljati analogni desetkanalni multimeter Kiethely, na katerega je mogoče z dodatno relejno kartico priključiti do 10 zaznaval. Kartica ima 10 relejev, ki preklapljajo med 10 kanali. Merilnik namreč lahko meri samo eno vrednost naenkrat. To za meritev zadostuje, kajti počakamo, da dosežemo ustaljeno stanje in nato preberemo rezultate.

Merilno verigo (sl. 1) sestavljajo naslednje komponente: žaromet (1), 10 uporovnih merilnih zaznaval Pt-1000 (2), univerzalni analogni merilni

analysis with the finite-element method (FEM). The measurements with the thermal camera also showed, that the temperature fields of different fog lamps look very similar to each other: the temperature falls linearly with the height and depth coordinates. The results also showed a local temperature peak above the bulb.

In the past the main sensor for measuring temperature was the thermocouple. The main drawback with a thermocouple is the enormous effort associated with positioning the sensor exactly on the surface of the part being measured.

The results from the measurement were later used to determine the approximation temperature function. A determination of the exact surface temperature and its distribution over the lamp casing is very important for the thermal analysis of the headlamp ([5] and [6]). The measurement procedures were automated, which also helped when performing the statistical analysis.

The results of the measurement and the determination of the temperature field of the housing will help in the development of new fog headlamps because fewer temperature measurements are needed. In the early development stages the results will make it possible to perform a thermo-mechanical FEM analysis without building prototypes. With this kind of development a faster and cheaper development process is ensured as eliminations of temperature-caused defects in the early development stages. This kind of development is also in accordance with Reliability Maintainability and Supportability (RMS) R&D procedures.

The measurement procedure for estimating the temperature field will be presented using an example of a fog headlamp from the company Saturnus avtooprema Ltd.

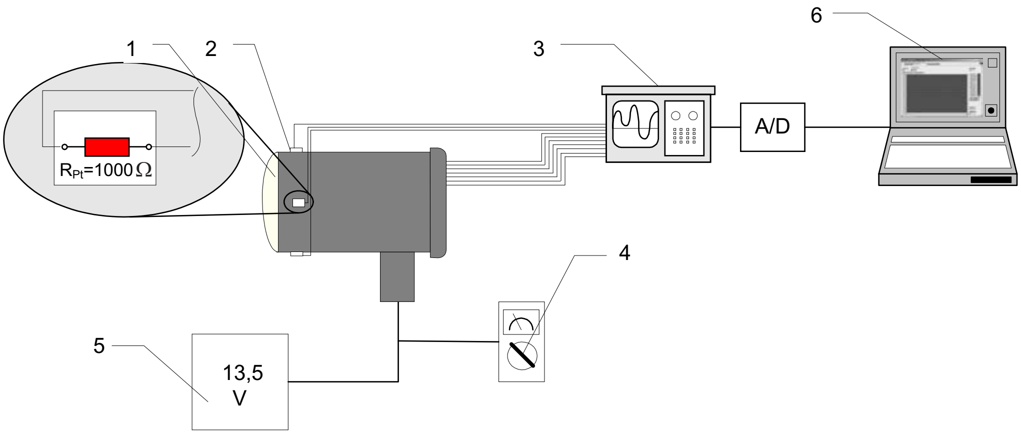
1 PREPARING THE EXPERIMENT

In this experiment the measuring chain was designed and a computer program for the data acquisition and storage was written. The measuring chain was calibrated and the measurements, which were statistically calculated, were preformed.

1.1 Measuring chain concept

The measurements were made using 10 Pt-1000 resistance-temperature detectors (RTD) with linear characteristics. A twin-wire method and a Kiethely analog 10-channel multimeter with a 10-relay measuring card was used. The measuring unit can measure only one value at a time, but with the help of the relay card the unit can switch over to different measured channels. Although only one value at a time can measured, this was sufficient for our purpose because we want to determine the steady temperature state.

The measuring chain (Fig. 1) has the following components: a fog headlamp (1), 10 Pt-1000 RTD sensors (2), a universal analog measuring



Sl. 1. *Shema merilne verige*
Fig. 1. *Scheme of the measuring chain*

inštrument Keithely, model 2000 (3), voltmeter (4), laboratorijski napajalnik (5), osebni računalnik s programskim paketom LabVIEW (6).

Zahtevana napetost na žarnici je 13,5 V. Napetost na žarnici merimo na sponkah žarnice z uporabo voltmetra (sl. 1).

1.2 Izbira uporovnih temperaturnih zaznaval

Pri merjenju temperatur, toplotnih tokov ali toplotne energije se največ uporabljajo dotikalna zaznavala [3]. Glavno vodilo pri izbiri zaznaval je pomenilo dejstvo, da se zaradi postavitve zaznaval lokalno ne spremeni odvod toplote. Iz tega pogoja je nastala tudi zadrega pri izbiri, kajti termočleni so manjši, zato je manjši tudi odvod toplote prek zaznavala in priključnih žic. Slaba stran termočlenov pa je natančno merjenje temperature na površini, kajti zaradi same oblike le tega težko zagotovimo namestitev zaznavala na površino. Najpogosteje se za merjenje temperatur uporabljajo uporovna temperaturna merilna zaznavala. Med uporovnimi temperaturnimi merilnimi zaznavali so največ v uporabi platinasta. Dobra lastnost platinastih zaznaval je linearna odvisnost spremembe upornosti od temperature v širokem temperaturnem področju.

Za meritev smo uporabljali uporovna zaznavala nemškega podjetja Heraeus Sensors. Namenjena so za meritve, kjer sta pomembna dolgoročna stabilnost in natančnost zaznavala. Oznaka Pt-1000 pomeni, da je merilna rešetka narejena iz platine in imajo imensko upornost pri 0 °C 1000 Ω. Rešetka je nanesena na keramični osnovi, kar zagotavlja dobro prevodnost toplote. Zaznavala Pt-1000 so tretjina merilne točnosti B. Tudi sama velikost zaznavala (4 mm × 2 mm) zagotavlja majhen odvod toplote prek zaznavala.

1.2.1 Lega in namestitev zaznaval

Zaznavala so nameščena na zunanji (zaznavala št. 3, 7 ,9) in notranji strani (zaznavala št. 4, 8, 10) okrova žarometa (zaznavala so drug nad drugim) in na notranji strani pokrova (zaznavali št. 1, 2) okrova ter na paraboli (zaznavalo št. 6) in senčniku (zaznavalo

instrument (Keithely, model 2000) (3), a voltmeter (4), a laboratory voltage source (5), a personal computer with the LabVIEW program (6).

The required voltage across the bulb is 13.5 V. The voltage is measured with the voltmeter (Fig. 1).

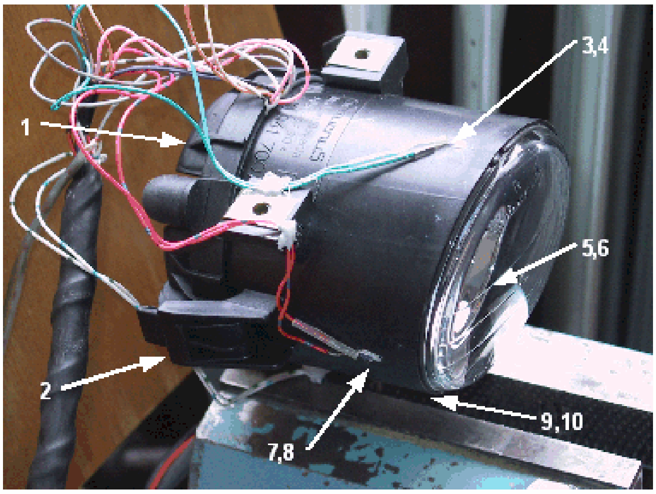
1.2 Temperature sensor selection

Measurements of temperature, heat flow or heat energy are usually made with contact sensors [3]. The basic rule for choosing a sensor is that the sensor should not locally change the heat flow. This problem is associated with thermocouples size. They are small, so a small heat flow is transferred through the sensor and its wiring; however, on the other hand, due to their shape it is hard to position thermocouples directly on the surface. The other most common method for temperature measurements is the use of RTD sensors. These sensors are usually made from platinum. RTD sensors also have a wide temperature range and a linear relationship between resistance and temperature change.

The measurements were made with RTD sensors from Heraeus Sensors. These sensors are used in cases where long-term stability and accuracy are needed. They are made from platinum and have a nominal resistance of 1000Ω at 0°C. The base on which the platinum wire is placed is made of ceramic, which offers good heat conduction. The sensors are in the tolerance class 1/3. Because of their small size (4 mm × 2 mm), heat conduction through the sensor is minimized.

1.2.1 Sensor position and fixation

The RTD sensors are mounted on the outer (sensors No. 3, 7, 9) and inner (sensors No. 4, 8, 10) sides of the fog-lamp housing (the sensors are one above another). Four other sensors are on the inner side of the housing lead (sensors No. 1, 2), on the



Sl. 2. *Namestitev zaznaval na zunanji strani okrova*
Fig. 2. *Positioning of the sensors on the lamp housing*

št. 5) žarometa (sl. 2). Lega zaznaval 3 in 4 je bila izbrana kot predvidoma najbolj vroče mesto na okrovu, in sicer točno nad mestom žarnice. Preostala zaznavala so postavljena tako, da bomo lahko dobljene vrednosti uporabili za izračun funkcije porazdelitve temperature po celotnem žarometu. Zaznavalo na senčniku ter na paraboli je postavljeno na najbolj vroči mesti.

Zaznavala prilepimo na površino merjenca z lepilom. Pri merjenju temperature je treba posebej paziti, da ima lepilo enako toplotno prevodnost in enako temperaturno razteznost. Plast lepila, s katero je zaznavalo prilepljeno, mora biti čim tanjša. Lepilo mora biti tudi temperaturno obstojno. Za lepljenje zaznaval na plastičen okrov smo uporabili dvokomponentno lepilo, ki je temperaturno obstojno do 250 °C. Ker je pričakovana temperatura na senčniku in paraboli zelo visoka (500 °C), je lepljenje zaznaval velik problem. Zaznavali, prilepljeni na kovinsko parabolo in senčnik, sta prilepljeni z uporabo tekoče kovine, ki je namenjena zalivanju razpok na kovinskih delih. To lepilo ima zelo podobno toplotno prevodnost kakor železo. Problem pa je bil pri obeh lepilih zagotoviti čim manjšo debelino lepila. Dodatne meritve s sevalnim infrardečim inštrumentom za merjenje temperature so pokazale, da je vpliv lepila na meritev zanemarljiv.

1.3 Program za zbiranje podatkov

Program za zbiranje podatkov in nadzor meritev sta narejena s programskim paketom LabVIEW. Kakor je razvidno s slike merilne verige (sl. 1), peljemo signale prek kartice za zbiranje več signalov na univerzalni analogni merilni inštrument, od tod pa na vzporedni vhod računalnika, kjer signale obdelamo in analiziramo s programskim paketom LabVIEW.

Program omogoča zagon, vodenje in nadzor celotnega postopka. Na prednji plošči programa so krmilniki in kazala s katerimi se merilni postopek vodi in nadzira.

parabola (sensor No. 6) and on the lampshade (sensor No. 5) as shown in Fig. 2. The sensors No.3 and No.4 are positioned on the hottest spot of the housing – above the bulb. The other sensors are positioned so that their results can be used for a calculation of a distribution function over the whole lamp housing. The sensors on the parabola and the lampshade are positioned on the hottest spots.

The sensors are fixed on the surface with an adhesive. The adhesive has the same heat-conduction and temperature-extension coefficient as the sensors. The layer thickens of adhesive has to be as thin as possible. The adhesive should withstand high temperatures. A two-component adhesive that withstands temperatures up to 250 °C was chosen. The expected temperatures on the parabola and the lampshade will be around 500 °C. This presents a huge problem for fixing the sensors. A liquid steel was used, which is used for the cold welding of cracks in metal parts. It has very similar heat-conduction properties to iron. The biggest problem is to ensure that the layer of the adhesive is thin. The influence of the adhesive was tested with an infrared temperature-measurement instrument, which showed that the influence of the adhesive was negligible.

1.3 Data-acquisition program

A data acquisition program was written with the LabVIEW program. As shown in Fig.1, the signals are directed to the measuring card in an analog measuring instrument and then to the parallel port of a PC, where they are processed and analyzed with the help of LabVIEW.

The program enables us to start, control and observe the whole measurement. The front panel of the program has controllers and indicators to control the measuring process.

2 MERITVE IN REZULTATI

Meritev je potekala pri nespremenljivi napetosti na žarnici 13,5 V. Posamezna meritev je trajala več ko eno uro, ker je morala temperatura doseči ustaljeno stanje. Meritev je potekala na 12 različnih mestih, merilni inštrument pa je imel možnost zbiranja samo desetih podatkov, zato je bilo treba meriti dva parametra posebej. To smo storili tako, da smo pokrov okrova z zaznavali odstranili in namesto njih priključili zaznavali na paraboli in senčniku ter meritev ponovili.

2.1 Preverjanje umerjanja merilne verige

Zaznavala Pt-1000 so izdelana iz platine, kateri se s spremembo temperature spreminja upornost. Merilno verigo smo umerjali tako, da smo žaromet s priključenimi zaznavali dali v toplotno komoro in primerjali izhodni signal oz. temperaturo zaznaval in etalonskega termometra. Etalonski termometer je bil na isti višini in na mestu kakor druga zaznavala, zato lahko vzamemo, da je na tem delu komore homogeno temperaturno polje. Merilno verigo smo preverjali pri temperaturah 20 °C, 40 °C ter 60 °C. Etalonski termometer ima merilno negotovost ±0,01°C. Primerjavo med temperaturo, izmerjeno z zaznavali Pt-1000 in etalonskim termometrom, prikazuje slika 3.

Opazimo lahko temperaturni odmik navzgor od etalonskega termometra. Pri 40 °C se pokažejo kar velika nihanja temperature v temperaturni komori (sl. 3). Vendar se pokaže, da niso sporna zaznavala, ker ta

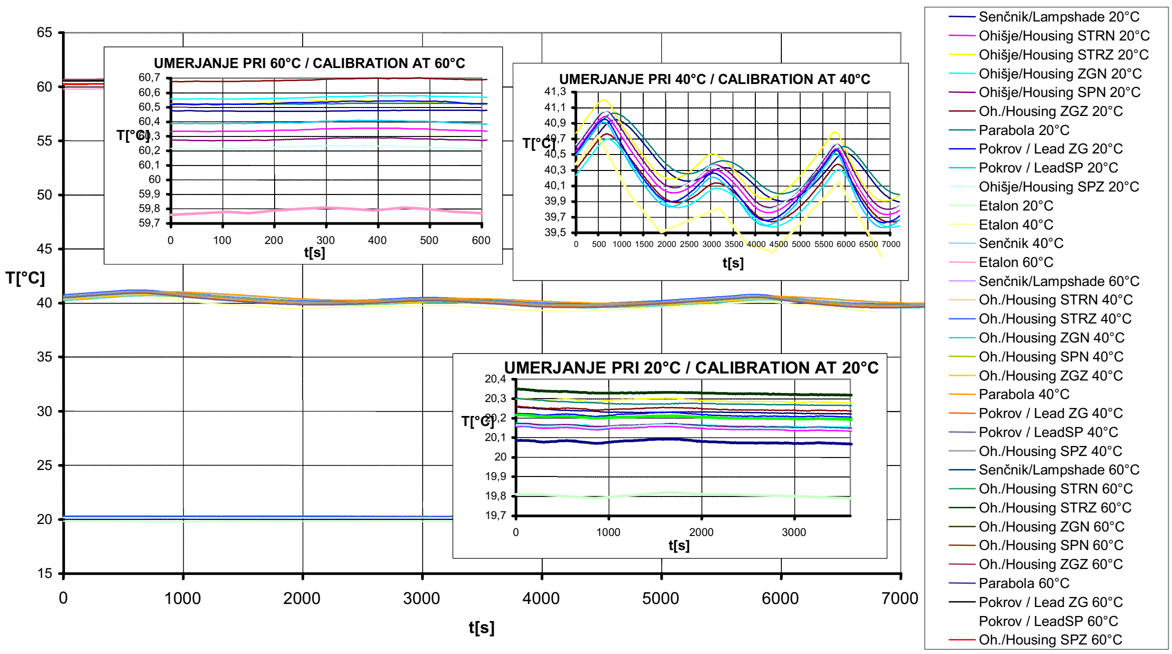
2 MEASUREMENTS AND RESULTS

The bulb was powered with a constant voltage of 13.5V. The measurement lasted more than an hour, because the temperature field needed to reach a steady state. Measurement was taken at 12 different spots, so two spots had to be measured separately. This is the way we measured all the spots on the housing and the lead. The sensors on the lead were then disconnetcted and the sensors on the parabola and the lampshade were connected and the whole measurement was repeated.

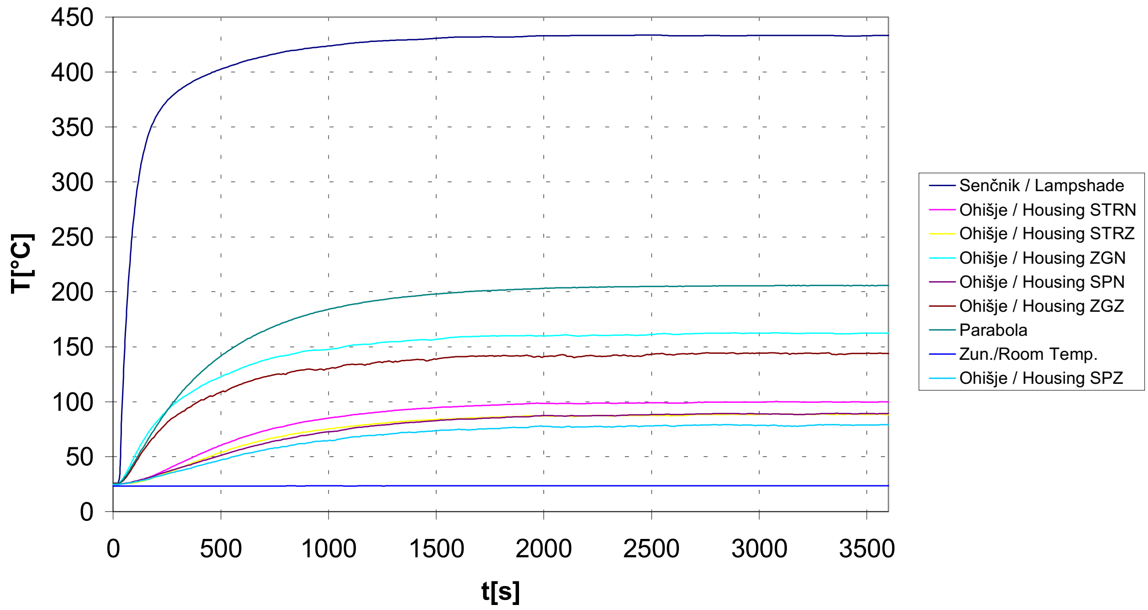
2.1 Measuring chain verification

The Pt-1000sensors are made from platinum, the resistance of which varies with temperature. The whole measuring chain together with the lamp was verified in a heat chamber and a temperature comparison was made with an etalon thermometer. The etalon thermometer was at the same height as the other sensors and we assumed a homogeneous temperature distribution in that part of the temperature chamber. The measuring chain was verified at the temperatures 20°C, 40°C and 60°C. The etalon thermometer has a measurement uncertainty ±0.01°C. The results of the Pt-1000 sensor verification are shown in Fig.3.

A positive temperature offset was observed for the sensors. A temperature oscillation at 40°C (Fig.3) was also detected. The problem of the oscillation is related to the heating chamber, which



Sl. 3. *Odstopek zaznavala od etalonskega termometra pri različnih temperaturah*
Fig. 3. *Verification of the sensors using an etalon thermometer*



Sl. 4. *Meritev temperature na okrovu in pokrovu žarometa*
Fig. 4. *Temperature measurement on the housing and the lead of the fog lamp*

lepo sledijo kalibracijskemu termometru, temveč komora, ki težko vzdržuje nespremenljivo temperaturo 40 °C. Amplituda nihanja temperature pri zaznavalih je 1,9 °C.

Iz meritev je razvidno, da kažejo zaznavala Pt-1000 nekaj višjo temperaturo kakor etalonski termometer. Opazimo pa lahko, da zaznavala lepo sledijo spremembam temperature in so zelo stabilna. Zaradi razlike med zaznavali in etalonskim termometrom izračunamo merilno negotovost merilne verige [4].

2.2 Rezultati meritev

Meritve so potekale v dveh delih, ker smo imeli na voljo omejeno število merilnih mest.

Tako smo najprej izvedli meritve na osmih merilnih mestih in dveh mestih na pokrovu žarometa. Nato smo zamenjali pokrov žarometa ter parabolo s senčnikom, kjer sta bili dodatni merilni mesti in ponovili meritve. Tako smo dobili 4 meritve temperature na pokrovu žarometa in 8 meritev na senčniku in paraboli. Za preostala merilna mesta smo dobili 12 meritev. Primer rezultata meritve je na zgornji sliki (sl. 4).

Za nadaljnjo obdelavo podatkov smo vzeli odčitke temperature po času 3000 s, kjer se temperatura ustali. Nato smo za vsako merilno mesto posebej izračunali povprečno vrednost ter 95-odstotni interval zaupanja za izmerjeno temperaturo. Spodnja slika prikazuje temperaturo v ustaljenem stanju, srednjo vrednost ter spodnjo in zgornjo mejo 95-odstotnega območja zaupanja za eno izmed merilnih mest (sl. 5).

Iz primerjave leve in desne strani na zgornji sliki za zaznavalo na notranji in zunanji strani vidimo

cannot be kept at a constant 40°C. At 40°C the sensors follow the etalon thermometer closely. The amplitude of the temperature oscillations at 40°C is 1.9°C.

The verification measurements show that the Pt-1000 sensors show higher temperatures then the etalon thermometer. The verification measurements also show that the sensors follow the changes in temperature very well, and that they are very stable. Based on the differences in the measurements between the sensors and the etalon thermometer the measurement uncertainty of the measuring chain was calculated [4].

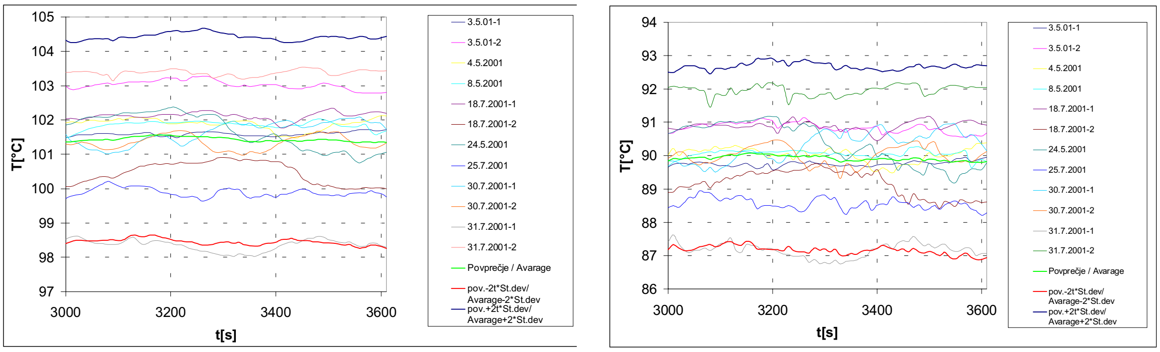
2.2 Results

Because of the limited number of measuring points, the measurements were carried out in two parts.

First the measurements were carried out on the eight points on the housing and the two points on the lead of the housing. Then the lead of the housing, the parabola and the lampshade were changed, so that the temperature on the parabola and the lampshade were measured. Altogether, four measurements on the lead and eight measurements on the parabola and the lampshade were made. An example of the measurement is shown in Fig. 4.

For subsequent analysis, the results after 3000 s were taken, because after this time the temperatures were stable. From these data a mean value and a 95% confidence interval were calculated. Fig. 5 shows the measurements at steady state for one measuring point, the mean value, and the lower and upper 95% confidence intervals.

From a comparison of the left- and right-hand side of Fig.5, which shows the results for the inner and outer sensors, the large influence of heat



Sl. 5. *Ustaljena temp. na zunanji (desno) in notranji (levo) stran srednjega dela okrova*
Fig.5. *The steady temperature on the outer (right) and the inner (left) sides of the middle part of the housing*

močan vpliv odvoda toplote zaradi cirkulacije zraka v prostoru okrog zunanjih zaznaval (sl. 5). Ta nastane zaradi prepiha oziroma drugih motenj. Na notranjih zaznavalih se ta vpliv zmanjša (bolj gladka krivulja), pojavi se s časovnim odmikom.

Končni rezultati, ki upoštevajo še sistemsko ter naključno negotovost, so predstavljeni v preglednici 1. Temperature se s 95-odstotno verjetnostjo gibljejo v spodnjem intervalu zaupanja.

transfer, as a result of air flow circulation in the room, on the outer sensor can be observed. This influence is a result of the air circulation and other air distortions in the room. The influence of the air flow in the room is less influential on the inner sensor (the temperature curve is smoother and distortions are delayed).

The results presented in the Table 1 below also take into account a systematic and coincidental uncertainty. The presented temperatures lie within the confidence interval with a 95% probability.

3 SKLEPI

Kakor smo že poudarili, je pomembna pravilna izbira zaznavala, kajti toplotna zmogljivost žarometa je razmeroma majhna in je zato vsak pritrjeni element "velik" odvodnik toplote. To lahko povzroči,

3 CONCLUSIONS

A fog lamp has a relatively small heat capacity, and therefore choosing a sensor with a very small heat capacity is essential because each sensor acts as a big heat conductor. As a result, the measured

Preglednica 1. *Rezultati meritev temp. na posameznih delih žarometa*
Table 1. *Measuring results for the flog-lamp parts*

Merilno mesto/ Measuring point	Temperatura/ Temperature [°C]
Zunanja stran zgornjega dela okrova / Outer upper side of the housing (Oh. ZGZ)	144,6 ± 2,5
Notranja stran zgornjega dela okrova / Inner upper side of the housing (Oh. ZGN)	166,8 ± 2,9
Zunanja stran srednjega dela okrova / Outer middle side of the housing (Oh. STRZ)	89,9 ± 0,9
Notranja stran srednjega dela okrova / Inner middle side of the housing (Oh. STRN)	101,4 ± 1,0
Zunanja stran spodnjega dela okrova / Outer lower side of the housing (Oh. SPZ)	80,5 ± 1,0
Notranja stran spodnjega dela okrova / Inner lower side of the housing (Oh. SPN)	90,7 ± 1,0
Notranja stran zgornjega dela pokrova / Inner upper side of the lead (Pok. ZG)	98,3 ± 0,8
Notranja stran spodnjega dela pokrova / Inner lower side of the lead (Pok.SP)	77,6 ± 0,7
Notranja stran zgornjega dela parabole / Inner upper side on the parabola (Parabola)	206,3 ± 1,2
Zunanja stran zgornjega dela senčnika / Outer upper side of the lampshade (Senčnik)	434,1 ± 2,5

da je merjena temperatura na mestu zaznavala manjša od dejanske. Zaradi tega smo izbrali zaznavala s čim manjšo površino ter priključne žice s čim manjšim prerezom. Vse priključne žice so pritrjene tako, da se ne dotikajo okrova na mestih merjenja. S tem smo zmanjšali odvod toplote na minimum.

Meritve so tudi potrdile domnevo, da ima temperaturno polje v žarometu velik gradient. Ta nastane zaradi vpliva naravne konvekcije in sevanja žarnice. Pokazalo se je, da je največja temperatura na okrovu žarometa na mestu nad začetkom parabole, kjer se topel zrak dviga in lokalno segreva okrov. Na isti višini zadnjega dela okrova se temperatura zmanjša kar za 60°C. Pokazalo se je tudi, da se pojavi kar velika razlika v temperaturi zunanje in notranje površine. Zaradi razlike temperatur po obliki žarometa in temperaturnih razlik na površini žarometa pride do deformacije okrova žarometa, kar privede do netesnosti okrova. Z ugotovitvami, pridobljenimi z meritvami, smo določili temperaturno porazdelitveno funkcijo [4], ki je bila podlaga za nadaljnje analize z uporabo končnih elementov.

temperature is lower than the true one. That is why we selected sensors with a small area and a small wire cross-section. All the connecting wires do not touch the housing near the measuring points. This also reduced the heat transfer from the housing to a minimum.

The measurements also showed that the temperature field in the lamp has a high temperature gradient. This is a consequence of the two forms of heat transfer: natural convection and bulb radiation. The measurements showed that the highest temperature on the housing is right above the end of the parabola. On that part the hot air is rising and it locally heats the housing. At the same height on the back part of the housing the temperature is 60°C lower. The temperature difference between the inner and the outer housing surfaces is quite large. These differences on the housing surfaces cause housing deformation, which can lead to sealing problems with the housing. The measurement results helped us to determine a temperature distribution function [4]. This function was the basis for subsequent calculations with the finite-element method.

4 LITERATURA
4 REFERENCES

[1] Wagner, A. (2001) Eksperimentalno določanje temperaturnega stanja v ohišju žarometa za vozilo VW Lupo (seminarska naloga pri predmetu Eksperimentalne metode v raziskovanem delu). Ljubljana.

[2] Holman, J.P., W.J.Jr Gajda (1984) Experimental methods for engineers, IV.izdaja, *McGraw-Hill International Book Co.*, London, , ISBN 0-07-Y66337-8.

[3] Bajsić, I. (marec 2001). Primerjava temperaturnih merilnih zaznaval. Ljubljana.

[4] Wagner, A. (2003) Izboljšanje razvojnih vrednotenj z napovedovanjem zagotovljivosti izdelka. Magistrsko delo. *Univerza v Ljubljani, Fakulteta za strojništvo*. Ljubljana.

[5] Moore, W. I., E.S. Donovan, C.R. Powers (1999) Thermal analysis of automotive lamps using the ADINA-F coupled specular radiation and natural convection model. *Computers and Structures* 72, London, 17-30.

[6] Okada, Y., T. Nouzawa, T. Nakamura (2002) CFD analysis of the flow in an automotive head lamp. *JSAE Review* 23, 95-100.

[7] Shiozawa T., M. Yoneyama., K. Sakakibara, S. Goto, N. Tsuda, T. Saga, T. Kobayashi T. (2001) Thermal air flow analysis of an automotive headlamp: the PIV measurement and CFD calculation for a mass production model. *JSAE Review* 22, 245-252.

Naslov avtorjev: mag. Andrej Wagner
prof. dr. Ivan Bajsić
prof.dr. Matija Fajdiga
Fakulteta za strojništvo
Univerza v Ljubljani
Aškerčeva 6
1000 Ljubljana
andrej.wagner@fs.uni-lj.si
ivan.bajsic@fs.uni-lj.si
matija.fajdiga@fs.uni-lj.si

Authors' Address: Mag. Andrej Wagner
Prof. Dr.Ivan Bajsić
Prof.Dr. Matija Fajdiga
Faculty of Mechanical Eng.
University of Ljubljana
Aškerčeva 6
1000 Ljubljana, Slovenia
andrej.wagner@fs.uni-lj.si
ivan.bajsic@fs.uni-lj.si
matija.fajdiga@fs.uni-lj.si

Prejeto: Received: 27.11.2003
Sprejeto: Accepted: 8.4.2004
Odprto za diskusijo: 1 leto
Open for discussion: 1 year