TEKA Kom. Mot. i Energ. Roln. – OL PAN, 2011, 11, 354–362

THE IDENTIFICATION OF OPERATIONAL FAILURES OF THE HEATING, VENTILATION AND AIR-CONDITIONING CIRCUIT IN THE CAR BY MEANS OF THERMOVISION METHODS.

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Summary. The present article contains the description of proposed method for periodical inspection of the heating, ventilation and air-conditioning (HVAC) circuits by means of thermovision cameras. The methods of interpretation of the obtained results have been presented in order to carry out the diagnostics of heating circuit failures. The technical condition of the ventilation system (air supply ducts) has been evaluated without its dismantling. Furthermore, the article contains the presentation of thermovision examinations enabling the indication of the areas with the highest heat losses in an easy and fast manner for the engine as well as for the passenger cabin. This possibility is particularly important in the winter period.

Key words: thermogram, infrared measurements, heating circuit, thermovision camera, microclimate in motor vehicle.

INTRODUCTION

The comfort of travelling by cars is influenced by many factors encompassing the design solutions and the microclimate in the motor vehicle. The desirable inside temperature to be achieved will improve the travel comfort and the psycho-physical functions of both the driver and passenger will be affected positively [4, 7]. The temperature control is possible for front and rear, LH or RH seats individually, by means of modern heating and air-conditioning circuits installed in the vehicles owing to air stream stratification phenomenon. The purpose of such solution is to adapt the microclimate in the motor vehicle to the individual needs of travelling passengers.

The appropriate microclimate in a motor vehicle i.e. the temperature, its distribution and air humidity contribute among others to the following:

- pulse stabilization in travelling passengers;
- reduction of driver's reaction time;
- reduction of nervousness and hurry;
- reduction of the impact of allergic reactions thanks to the purification of supplied air (by means of anti-dust filters);

– achievement of temperature distribution optimal for the human body (warmer feet, cooler head).

The factors specified above directly contribute to the safety improvement in road traffic. Failure to meet them causes the feeling of discomfort by the driver as well as the passengers.

The optimal temperature in the passenger cabin should be included between the limits 23 – 26 °C in summer period (at outside temperature of 40 °C) and about 27 °C in winter period (at outside temperature of –20 °C) [1, 2, 7].

All inefficiencies of the heating and air-conditioning circuit, particularly in winter period can contribute to non-optimal use of thermal energy and consequently to the discontinuation of travel (e.g. as a result of panes freezing). Many years' operation of the cars leads to the electrical or mechanical failures as well as to the choking of ducts supplying the air to the vehicle interior.

THE THERMOVISION MEASUREMENTS AND THEIR ACCURACY

The quantities of additional equipment installed in motor vehicles change simultaneously with the development of the new design solutions in the cars. Their standard equipment encompasses the systems which were used a few years ago in the high class cars only. As a result of continuous technological development, the cars become more complex and problematic in case of potential repairs. Therefore, it is necessary to create new diagnostic procedures.

The thermovision examinations [13, 14, 15, 17] are used in the machines diagnostics more and more frequently. For a few years recently they have also been applied in the automotive sector, e.g. for the tyres wearing examination [10] or for qualitative evaluation of the vehicles used for food transportation [16]. The creation of fast and non-invasive methods of the technical condition evaluation for selected equipment was possible due to the relationship between the temperature conditions and the failure.

The thermovision examinations are based upon visualization of infrared radiation which is invisible for human eye and is emitted by a body with temperature higher than absolute zero. This property is defined as the emissivity factor i.e. ability of a body to hand over the energy. The emisissivity depends on the physico – chemical properties and is a unique feature of each object. The termovision camera is the device used for temperature measurement and analysis; the obtained image is called thermogram.

Owing to their advantages i.e. versatility and possibility of contactless temperature measurement, the thermovision examinations are perfectly suitable for the analysis of elements releasing certain amount of heat in course of their operation. The accuracy depends mainly on the applied method, device calibration and on the accuracy of thermovision camera. The most important are the errors associated with the applied method i.e. the following [8, 9, 11]:

– emissivity estimation errors,
– errors caused by the impact of the ambient radiation reflected by the object (e.g. solar radiation, street lighting),
– errors caused by the transmission of radiation through atmosphere,
– errors caused by the transmission of infrared radiation through the camera,
– errors caused by the impossibility of results averaging.

Owing to their values, even up to a few percent, these errors take priority in course of the termovision measurements. In course of the examinations presented in the present article, these errors have been minimized thanks to the application of an appropriate measurement procedure described in the chapter entitled "Examinations methodology".

THE HEATING, VENTILATION AND AIR-CONDITIONING (HVAC) CIRCUIT OF THE CAR

As mentioned above, the heating, ventilation and air-conditioning (HVAC) circuit performs an important role, particularly in case of unfavourable weather conditions, in the summer period (high temperature) as well as in the winter period (rain, snow, low temperature). From the functional point of view, the heating, ventilation and air-conditioning (HVAC) circuit constitutes a whole entity. The fresh air flows through the evaporator and is supplied to the interior of passenger cabin (temperature reduction) or additionally heated in the heater (temperature increase). The principle of cooperation between both the systems is illustrated in Figure 1. The "hot" or "cold" air cycle is established by means of a diaphragm which can be controlled in the mechanical mode by means of a cable or in the electrical mode by means of a mini motor.

The basic requirement to be met in the course of the designing and selection of the devices dedicated for the vehicle heating and air-conditioning is to achieve desirable temperature within assumed period of time. Owing to heat losses, the power determined for the equipment is higher than its value resulting from energy balance calculated for the specified vehicle body as well as for climatic conditions in which the car will be operated [6].

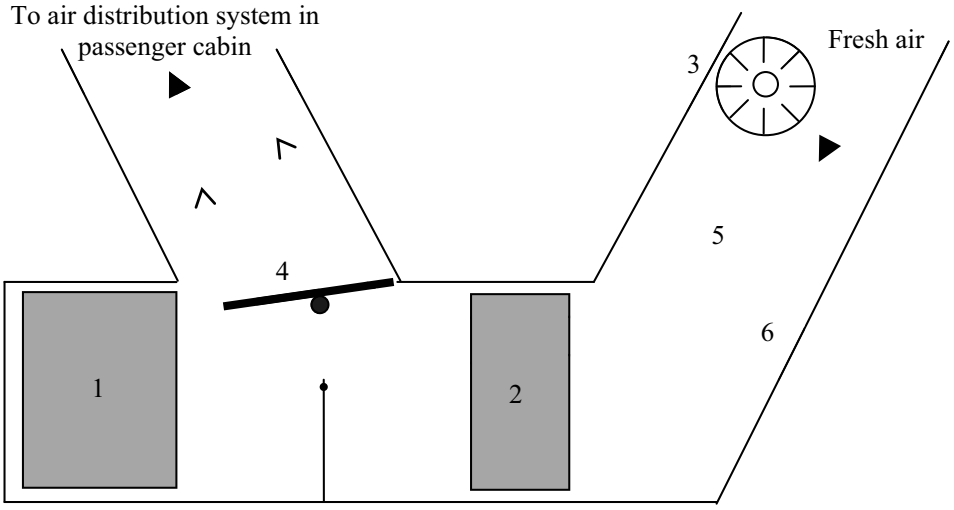

Fig. 1. The cooperation between the heating and air – conditioning system
1-heater; 2- evaporator; 3- blower; 4- hot and cold air diaphragm; 5- cold air; 6- hot air

The contemporary cars are provided with the possibility to control the temperature, humidity, air stream velocity and its stratification. The whole operation is monitored by ECC system (Electronic Climate Control) incorporating the electronic control system. The driver has the possibility to set the required operation parameters by means of the panel (Fig. 2).

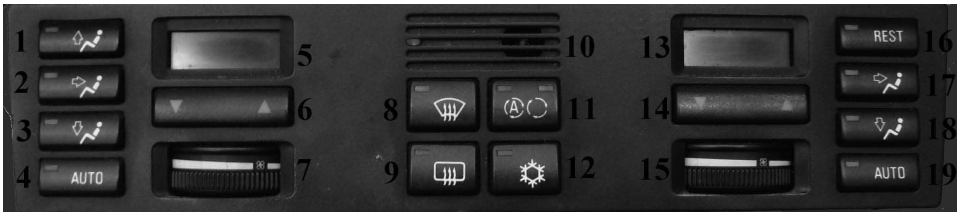

Fig. 2. Control panel for the heating and air – conditioning system installed in BMW cars (1994-2001)
1- air supply to windscreen / panes; 2 - air supply to the head (driver's side); 3 - air supply to the feet (driver's side); 4 – air – conditioning automatic control (driver's side); 5 – temperature indicator (driver's side); 6 – temperature control (driver's side); 7 – air supply intensity (driver's side); 8 – defrosting function; 9 – rear pane heating; 13 – vehicle inner temperature sensor; 11 – closed loop air cycle; 12 - air – conditioning ON; 13 – temperature indicator (passenger's side); 14 – temperature control (passenger's side); 15 - – air supply intensity (passenger's side); 16 – residual heat utilization; 17 - air supply to the head (passenger's side); 18 - air supply to the feet (passenger's side); 19 – air – conditioning automatic control (passenger's side);

The basic functions of the „control panel" are: manual temperature setting by the driver and passenger separately, defrosting of the windscreen and side panes, electric defrosting of rear pane as well as closed loop cycle mode and residual heat utilization mode. In the closed loop cycle mode (pushbutton 11, Fig. 2) the diaphragm supplying fresh outside air is closed and air is circulated in the car interior in order to ensure its faster heating. The residual heat utilization mode (pushbutton 16, Fig. 2) enables the car heating after engine shutoff. The heat contained in the engine cooling medium is used for this purpose. Irrespective of differences in the construction of the heating and air – conditioning systems, the majority of their functions is identical independently on the model of the vehicle.

EXAMINATIONS METHODOLOGY

Owing to the application of an electronic system for the heating and air – conditioning circuit operation control, the diagnostics procedure is carried out by means of the diagnostic testers or by means of devices dedicated for the inspection of air – conditioning systems in the cars. The procedures and the manner of proceeding in course of repair are widely described in literature [1, 3, 5]. However, this article presents the proposal of the evaluation of the technical condition of structural elements of the vehicle which affect the maintenance of specified temperature in the car. It is impossible to detect these failures by means of a/m devices. The examinations were carried out for those parts (circuits) of vehicle which can be potentially damaged during everyday operation owing to the ageing of elements or to mechanical processes (gaskets, ventilation ducts, rear pane heating circuit etc.). This issue is particularly important in the winter period with high difference of temperatures inside and outside of vehicle. All leaks and failures can lead to the necessity of stopping the travel.

The examinations have been performed by means of ThermaCAM E45 thermovision camera manufactured by FLIR. The following criteria have been established in order to minimize the measurement inaccuracies described in the preceding chapter:

a) owing to the lack of information about the material used for the fabrication of the bodies of the cars being tested and for the fabrication of other components of the motor – car body, a black tape with known emissivity was adhesive-bonded every time onto the element being tested in order to determine the correct value of emissivity factor;

b) owing to significant impact of weather conditions on the obtained results, days selected for the examinations were characterized by the weather free of any significant meteorological changes in the course of three successive days (72 hours);
c) owing to results accuracy, the impact of atmospheric radiation and the impact of the radiation reflected from the object being tested were minimized, because the measurements were performed at night and cloudy sky, far from street lighting;
d) the measurements for semi – transparent and transparent components (car panes / windscreen) have been performed in accordance with requirements included in the literature [12] (correct value of emissivity factor and of transfer coefficient);
e) the cars under examinations were heated up to the temperature of passenger cabin i.e. about 25 °C (the difference between the inside and outside temperature was equal to about 35 °C).

It was possible to obtain objective results and to maintain the minimization of measuring error, because the criteria presented above have been met.

THE RESULTS OF EXAMINATIONS – THERMOVISION PICTURES

All damages in the scope of the heat insulation system of the car and in the scope of heating circuit, particularly in winter period, lead to non- optimal use of thermal energy. They can also cause the panes freezing and consequently the loss of visibility. The engine temperature is reduced as a result of high heat demand. Therefore, the fuel consumption is increased.

The thermograms included below represent the areas with the leaks and failures occurred as a result of everyday operation of vehicle and as a result of structural components ageing. The gaskets located between the cabin doors and the car body are the elements producing the highest heat losses (Fig. 3a). The determination of heat loss percentage is possible by means of computerized analysis of the obtained results for every location being examined (the arrows indicate the maximum heat losses in the surface under analysis - Fig. 3b).

a) b)

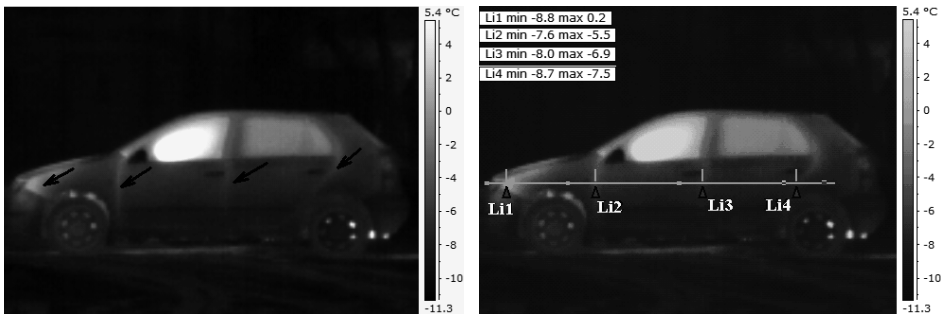

Fig. 3. Thermogram of the car:
a) locations of occurring heat losses;
b) Temperature values at the locations of occurring heat losses

This method is used in order to qualify an element (gasket) for potential replacement. Ar1 point (Fig. 3b) situated in the vicinity of the engine chamber represents the highest heat losses in the thermogram under analysis.

The choked ventilation ducts distributing the air in the car are frequently the reason of the heating circuit inefficiency caused by the contaminations penetrating through the cabin filter used over long period of time without replacement. Another possible reason is the physical damage of ducts occurring as a result of excessive temperature or repair works.

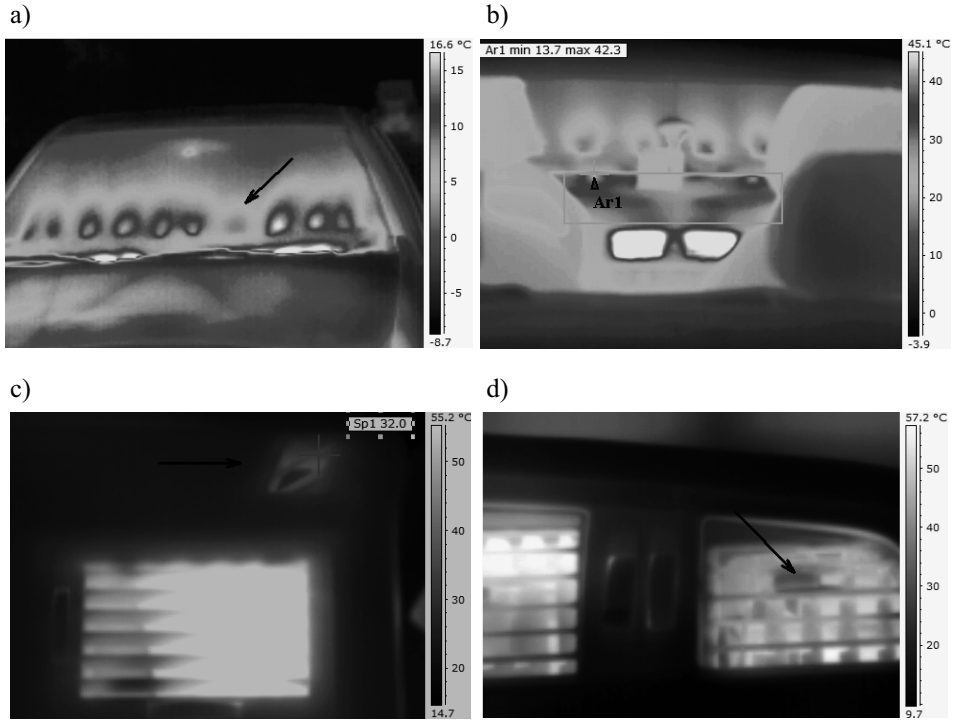

Fig. 4. Thermograms of air distribution circuit in the passenger cabin
a) windscreen; b) dashboard of the car (central panel);
c) side air grilles; d) central air grilles

The examples of the failures described above are illustrated in Figure 4:

– blocked air grille heating the windscreen causes its non-uniform defrosting (Fig. 4a) and can consequently lead to the visibility loss for the driver;
– properly heated air distribution system in the car makes it possible to perform the analysis of failures inside the ventilation ducts without dismantling e.g. dashboard (Fig. 4b). Furthermore the thermovision pictures give the opportunity to evaluate the warming – up of the dashboard i.e. a phenomenon associated with the use of proper materials and insulation elements;
– blocked side grille causes the loss of visibility in the mirrors (lack of defrosting of the windscreen areas situated in the vicinity of the mirror – Fig. 4c);
– failure (breaking) of air grille occurring in the form of non-uniform heat distribution at outlet (Fig. 4d).

The thermovision examinations make it also possible to quickly localize the physical damages causing the heat losses (Fig. 5a) and the discontinuities in the rear pane electric heating circuit of the car (Fig. 5b).

a) b)

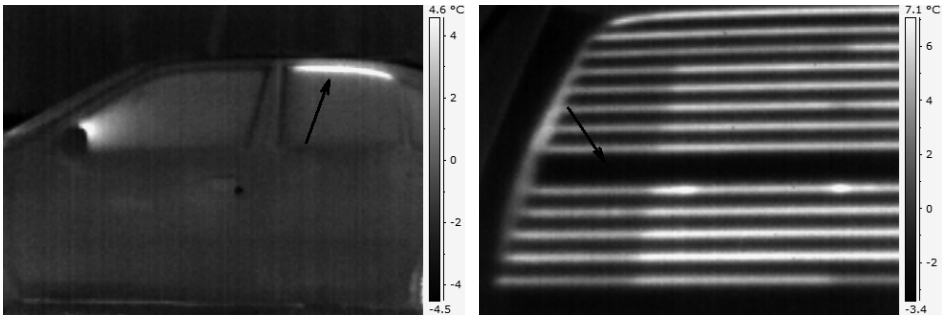

Fig. 5. Thermograms of failures
a) physical damage of the body in vicinity of rear pane,
b) discontinuity of rear pane heating path

CONCLUSIONS

1. The examinations presented in this article demonstrated that the thermovision can be used for the diagnostics of selected elements, systems or the whole circuits of motor vehicles in an easy and fast manner. The appropriate interpretation of the obtained results – thermovision pictures is the prerequisite for its application.
2. The efficient operation of the heating and air – conditioning system affects the travel comfort, reduces the driver fatigue and consequently increases the road traffic safety.
3. The method of examinations presented in this article can be applied in the summer as well as in winter period. However, the efforts should be made in order to maintain the highest possible difference between the temperature in the passenger cabin interior and outside temperature (more accurate interpretation of the results).
4. Using the thermovision cameras, it is possible to evaluate the vehicle insulation condition in a fast manner and to indicate the locations potentially endangered by failures. This method enables the detection of operational, design and technological defects of the car.
5. As a result of precise computerized analysis of the obtained results (thermograms) it is possible to classify an element or the whole system (circuit) as an inefficient component. The thermovision pictures are the diagnostic symptoms ensuring the detection of damaged location in a fast and reliable manner.
6. The thermovision examinations are an objective, non – invasive and contactless method used for the evaluation of technical condition of the heating, ventilation and air-conditioning (HVAC) circuit enabling the obtainment of diagnostic data without necessity to dismantle its individual elements.
7. The thermovision pictures can be used as database helpful in the design of new solutions, the improvement of reliability and performance of the heating, ventilation and air-conditioning circuits.

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IDENTYFIKACJA USZKODZEŃ EKSPLOATACYJNYCH OBWODU OGRZEWANIA, WENTYLACJI I KLIMATYZACJI SAMOCHODU Z WYKORZYSTANIEM TERMOWIZJI

Streszczenie. W niniejszym artykule zaproponowano metodę okresowej kontroli obwodów ogrzewania, wentylacji i klimatyzacji z zastosowaniem kamer termowizyjnych. Przedstawiono sposoby interpretacji otrzymanych wyników w celu zdiagnozowania uszkodzeń obwodu ogrzewania. Dokonano oceny stanu technicznego instalacji wentylacyjnej (kanałów doprowadzających powietrze) bez jej demontażu. W artykule przedstawiono ponadto badania termowizyjne, które pozwalają w szybki i łatwy sposób wskazać miejsca występowania największych strat ciepła zarówno silnika, jak i kabiny pasażerskiej, co jest szczególnie ważne w okresie zimowym.

Słowa kluczowe: termogram, pomiary w podczerwieni, obwód ogrzewania, kamera termowizyjna, mikroklimat w pojeździe.