# NEW SOLUTIONS FOR IMPROVING THE VEHICLE HEATING SYSTEM

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***Abstract:*** *The specific requirements of the air-conditioning system are in connection with maintaining the optimal thermal comfort for the vehicle occupants and providing a good visibility through the windscreen. This is a real challenge due to the extreme weather conditions experienced across the globe. The heating method, by using the cooling system of the engine, takes a lot of time to heat the interior air. Auxiliary electrical and booster devices are proposed to improve the heating of the vehicle compartment. The paper is focused on analyzing the different technologies available and developed in order to provide the heat necessary for assuring the thermal comfort of the vehicle passengers. Measurements on a PTC heater are made and analysed.*

***Key words:*** *heating, positive temperature coefficient, engine, vehicle.*

## 1. Introduction

Modern internal combustion engines (gasoline and diesel) offer improved efficiency and dissipate less heat to the cooling system of the engine. In winter time, these engines produce little excess heat - especially in city traffic and traffic jams - out of whom the heating systems relying on engine heat are unable to provide quickly the desired amount of heat for warming the passenger’s compartment up to a comfortable level.

There are different technologies available to provide the heat and to quickly obtain the passenger’s thermal comfort: conventional heating method, electrical heaters and booster heaters.

Generally, the heat from the cooling system of the internal combustion engine (ICE) is used for heating the vehicle interior air.

Due to the specific roles of the cooling systems - to protect from overheating and to maintain a constant temperature of the internal combustion engine - the dissipated heat is reduced and variable.

Thus, the heating method using the cooling system of the ICE is unsatisfactory: the interior air temperature increases slowly, especially in winter time.

To improve the conventional heating method, auxiliary heating devices are proposed.

This paper describes and analyses different methods developed to provide the necessary heat for assuring the passenger’s thermal comfort. Also, measurements on a positive temperature coefficient (PTC) heater are made and analysed.

## 2. Conventional Heating System

Generally, two types of ICE cooling systems are used on vehicles: liquid cooled systems and air cooled systems [4].

Air cooled systems are used on older vehicles and on very few modern vehicles.

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Instead of circulating fluid through the ICE, the engine block is covered in aluminium fins that conduct the heat away from the cylinder. A powerful fan blows the air over these fins, which cools the engine by transferring the heat to the air.

Liquid cooled systems are proposed for the modern vehicles. The fluid used by liquid cooled systems must have a very low freezing point, a high boiling point and the capacity to hold a lot of heat. Water is a common liquid used for holding heat, but its freezing point is too high (0 °C) and that's why it is not used in the engine cooling systems of the vehicle.

Since ICE operates in a wide range of temperatures, the fluid used by liquid cooled systems consists in a mixture of water and ethylene glycol ($C_2H_6O_2$) - antifreeze, in order to improve the boiling and freezing points.

In Table 1, the main values are shown resulting from a statistic made on the freezing and boiling points for a mixture of water and ethylene glycol (antifreeze) at different concentrations.

*Freezing and boiling points for water and antifreeze* Table 1

| | | Quantity, [%] | Freezing points, [°C] | Boiling points, [°C] |
|---|---|---|---|---|
| **Pure water** | | 100 | 0 | 100 |
| **Anti freeze** | water | 50 | –20 | 106 |
| | $C_2H_6O_2$ | 50 | | |
| | water | 33 | –33 | 113 |
| | $C_2H_6O_2$ | 66 | | |

Since most vehicles use liquid cooled systems, the paper is focused on that system. Figure 1 describes the liquid cooling of the ICE system with its components are shown.

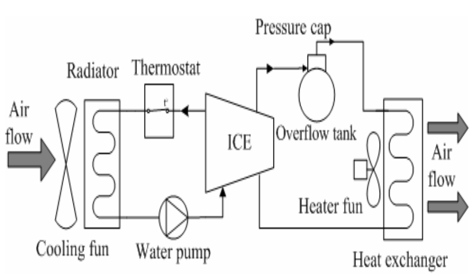


Fig. 1. *Liquid cooled system*

In Figure 2, there are illustrated the two circuits of the liquid cooled system:

1. *Primary circuit:* The coolant flows from the engine block, through the thermostat, to the radiator where it is cooled. Using the water pump, the coolant is carried back into the engine where it is heated again. The overflow tank keeps air out of the system and also replaces the water which was expelled from the circuit;

2. *Secondary circuit:* The heated coolant is carried then, through pipes, to the heat exchanger where the heated air is produced. The heater fan blows the heated air through the heat exchanger and then through air vents into the passenger compartment of the vehicle [8].

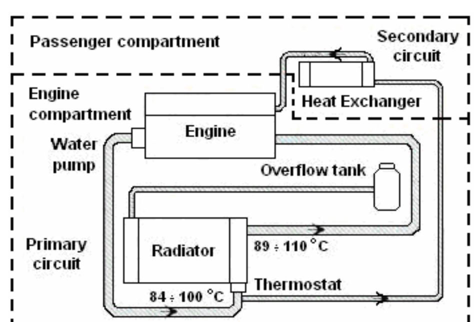


Fig. 2. *Diagram of a cooling system*

The thermostat allows the ICE to heat up the coolant quickly and then keeps a constant temperature. As long as the temperature of the coolant is below +90 °C, the thermostat remains closed, the flow to the radiator is blocked and the coolant flows back to the engine. When the coolant temperature is above +90 °C, the thermostat remains open.

If the thermostat is removed, then: (*i*) the engine will never reach its operating temperature and the fuel consumption and emissions will be increased; (*ii*) the coolant will flow fast and uncontrolled through the circuit and thus it will not be properly cooled (the engine can be overheated) [12].

The disadvantage of the conventional heating is that it takes a lot of time to heat the interior air and a lot of energy is wasted.

## 3. New Heating Solutions

In order to improve the conventional heating method, two auxiliary devices, such as the electrical device (positive temperature coefficient heater) and the fuel device (booster heater) are used.

### 3.1. Booster Heaters

The booster heater is an auxiliary device, which provides the heat, particularly, in the compartment of the utility vehicles.

The coolant picks up the heat from the combustion chamber of the booster heater. The heater fan blows the heated air through the heat exchanger and then through air vents into the passenger compartment of the utility vehicle.

The booster heater characteristics are:

- It uses air or coolant to transfer the heat into the vehicle interior;
- It functions with gasoline or diesel;
- It is used particularly for heating the large interior space (utility vehicles) or in extreme weather conditions experienced across the globe;
- Water flow of 650 l/h at 1500 rot/min.

The booster heater has two functions:

- preheating of the engine;
- preheating of the vehicle interior air.

The booster heater is situated in the engine compartment or under the vehicle chassis.

The booster heater unit is divided in four main sections:

- heat exchanger;
- combustion chamber;
- combustion blower;
- unit control module.

In Figure 3, there is shown a booster heater unit with its components: 1 - combustion blower; 2 - electrical blower; 3 - heat exchanger; 4 - combustion chamber; 5 - low plug; 6 - flame sensor; 7 - temperature sensor; 8 - overheating sensor; 9 - control module; 10 - air supply duct; 11 - noise reducer; 12 - fuel circuit; 13 - water pump; 14 - fuses box; 15 - electric connector; 16 - outlet bolt; 17 - metering pump; 18 - filter; A - exhaust; B - fuel supply; V - fresh air supply; WA - coolant outlet; WE - coolant inlet.

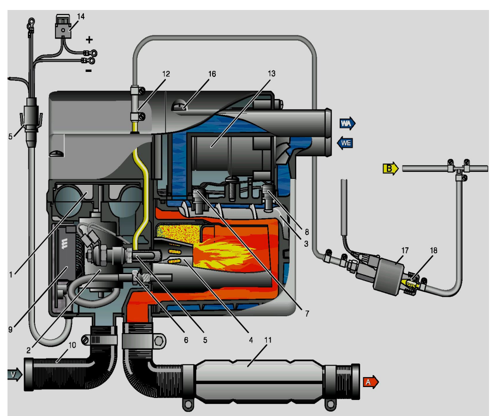

Fig. 3. *Booster heater unit* [16]

When the booster heater is controlled, the water pump, combustion blower, glow plug and the metering pump start producing the combustion. The coolant inlet supplies the heat exchanger of the booster heater unit, which allows the coolant to flow around the combustion chamber. The heat is transferred from the heat exchanger to the coolant. The heated coolant is then evacuated through the coolant outlet towards the vehicle heat exchanger. The heater fan blows the heated air, produced by the heat exchanger, in the passenger compartment.

Since the heating power depends on the coolant temperature, sensors are mounted to the heat exchanger housing, which monitor the coolant inlet and coolant outlet temperature. These values are used to control the temperature inside the booster heater. Temperature, overheating and flame sensors are used to prevent the booster heater unit from overheating. All these information are controlled and monitored by Electronic Control Module (ECM) of the vehicle.

The booster heater is connected to the vehicle electrical system and is controlled by ECM, the additional control panel and by relays.

In Figure 4, there is shown the booster heater control diagram.

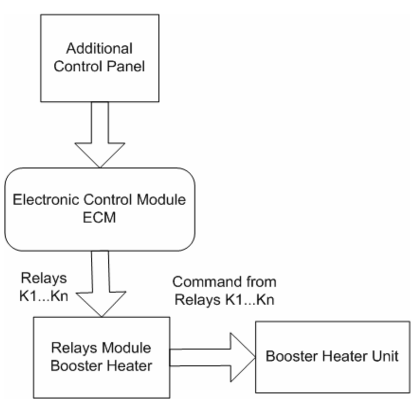


Fig. 4. *Booster heater control diagram*

Starting, regulating and controlling the booster heater are fully automatic and are easily integrated into a HVAC (Heating Ventilating and Air Conditioning) system.

In Figure 5, there are illustrated the integration of a booster heater in the cooling system and the circuit components: 1 - booster heater; 2 - water pump; 3 - thermostat; 4 - one-way valve; 5 - „T" profile; 6 - heat exchanger; 7 - vehicle engine.

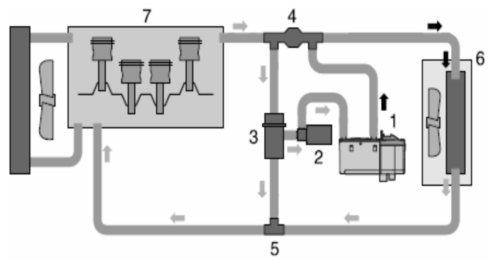


Fig. 5. *Integration of a booster heater in the ICE cooling system* [16]

As it can be seen in Figure 5, there are two cooling circuits:

- a small cooling circuit; as long as the thermostat is switched off, the coolant flows through the engine block, heating up;
- a large cooling circuit (engine, thermostat, water pump, booster heater, heat exchanger); as long as the coolant temperature increases, the thermostat switches on gradually. At 90 °C the thermostat is switched on entirely and the coolant flows in the booster heater, where it is further heated and then to the heat exchanger, where the heated air is produced. The heater fan blows the heated air into the passenger compartment.

The fuel supply of the booster heater is made directly from the vehicle tank. The quality of the fuel influences the functioning of the booster heater. Gasoline (DIN EN 228) or diesel (DIN EN 590) increases the booster heater performances.

The booster system is electronically controlled and it is switched off if:

(*i*) no ignition takes place;

(*ii*) the flame is extinguished during the operation and another attempt to start fails;

(*iii*) the overheating sensor responds at an overheating event;

(*iv*) the voltage is over- or undershot;

(*v*) the metering pump, temperature sensors or air blower are damaged.

Total electrical power consumption for the booster heater ranges between 1000 W and 3000 W. For example, at maximum value of the power (3000 W), the booster heater uses 0.38 L/h fuel and works in the temperature range of −40 °C to +80 °C. At +80 °C the booster heater stops.

Advantages of using a booster heater:

- it reduces the time for increasing the interior air temperature;
- it compensates the lower engine coolant temperature;
- it improves the visibility through windscreen.

### 3.2. PTC heaters

Positive temperature coefficient heater (also called PTC heater or PTC stone) is an auxiliary heating device.

Due to its self-adjustment properties, PTC heater can dispense with control and adjustment components, as well as with overheating protection. PTC heating elements can be designed to have different type of shapes: square, rectangular, round, or of ring, and they have aluminium, stainless steel or silicon casing.

The PTC heaters have a wide variety of applications such as:

• Household appliance: water heater, espresso and coffee machine, dishwasher;

• Industrial appliances: plastic film welder, mould heating, binding systems;

• Automotive appliance: vehicle interior heating, fuel preheating, engine preheating;

• Instrumentation heater.

The PTC heater characteristics are:

- rapid heating after starting the vehicle;
- safe through temperature limiting characteristics;
- no excess temperature protection required - the unit cannot overheat;
- dynamic, self regulating, and therefore energy efficient;
- power: 20 W to 2000 W;
- surface temperatures: 50 °C to 320 °C;
- light and compact design;
- long life service.

Commonly used PTC materials include high density polyethylene filled with graphite, polymeric and titanate ceramic materials, based on grain boundary effects. PTC heaters based on barium titanate ceramic are mostly used in automotive industry (high resistance and power-dissipation characteristics) [1], [5], [10], [14].

Over the years, various theoretical and experimental models have been developed to describe the PTC heater effect in semiconducting $BaTiO_3$, such as Heywang, Jonker and Wang. The most accepted model was Heywang model based on grain boundary potential barrier for semiconducting $BaTiO_3$ ceramics. This model explained the resistance-temperature dependencies of a $BaTiO_3$ ceramics [6], [7], [9], [11], [13].

In the automotive field, the PTC heater is proposed as auxiliary heating device in order to quickly obtain the thermal comfort of the vehicle passengers.

The PTC heater is mounted inside the HVAC system, after heat exchanger.

In Figure 6, there is illustrated the position of the PTC heater inside the HVAC system and the air flow through the HVAC.

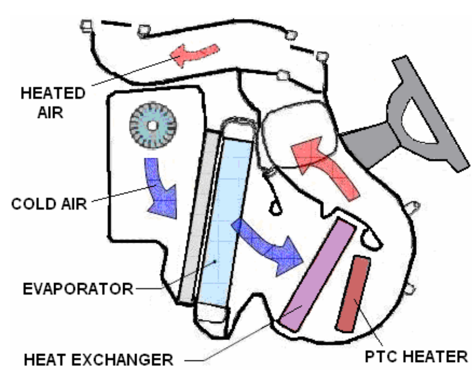


Fig. 6. *Air flow inside the HVAC*

The PTC heater is connected to the vehicle electrical system and controlled by the electronic control module (ECM), HVAC control panel and by relays [2].

In Figure 7, there is shown the PTC heater control diagram.

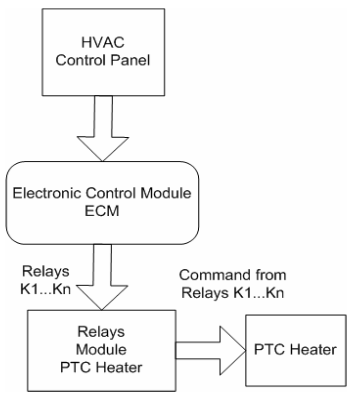


Fig. 7. *PTC heater control*

The PTC heater consists of a moulded plastic plate (1), an electrical connector (2) and heating resistive elements with fins (3).

In Figure 8, there is illustrated a PTC heater with its components.

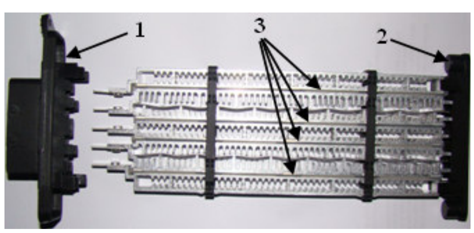


Fig. 8. *PTC heater components*

The heating resistive elements consist of small metallised ceramic plates (1), which are layered alternately along the unit core with aluminium radiator elements (2). These layers are held together by spring elements in a frame. The aluminium elements assure the electrical contacts and transfer the heat to the passing heater air flow [15].

In Figure 9, there are illustrated the PTC heating resistive elements.

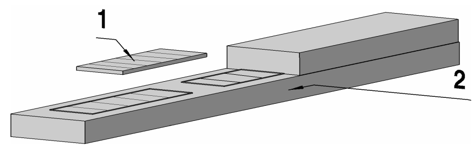


Fig. 9. *PTC Heating resistive elements*

The heater resistive elements are separated in different heating circuits in order to adapt the heating power to different requirements. PTC heater elements act as a positive temperature coefficient resistor. When a voltage is applied to the cold PTC elements, a high electric current is generated and the value of the resistance rises with the temperature. The effect is the reduction of the current intensity.

The heater temperature depends on the rate of heat transfer to the vehicle interior. The value of resistance can remain low if the heat transfer rate is good (a cold low humidity condition will have a greater temperature difference and allows for a greater rate of heat transfer). Once the air has warmed up, and the heat transfer rate reduces, the PTC heater will start to increase in temperature due to the inability to give up heat. This will cause the rise of the resistance on the unit and thus the reduction of the current, which will maintain or reduce the temperature. At the opposite side, the heater manages to give up heat to the interior of the vehicle, then the unit cools off and the value of resistance is reduced. This will increase its current flow and the temperature. Because of these specific resistance characteristics, it is not possible for the PTC heating elements to overheat [3].

The PTC heater operates only:

(*i*) at low external temperatures ($<T_c$);

(*ii*) when insufficient heat is supplied by ICE cooling system;

(*iii*) at reduced loads of the generator.

The PTC heater demands a large quantity of electrical energy, so it operates only when the engine is running. In order to reduce the factor demand of the generator, the PTC heater switches progressively the heating elements. In this case, the load of the generator will affect the idle speed and emissions.

Total electrical power consumption for the PTC heater ranges between 900 W and 2000 W, depending on the volume of the vehicle interior. Vehicles equipped with PTC heater are fitted with a more powerful generator.

In order to prevent load dumps and ECM problems caused by high currents and to have a more flexible control, a PTC heater is composed of 3-6 small heating resistive elements (200 W, 300 W or 400 W), controlled separately by relays.

## 4. Experimental Results

In order to design the PTC heater for vehicle thermal comfort system, the resistance - temperature dependency of PTC heaters $R$ = f($T$) is important.

To obtain the thermal characteristic, a test bench was developed. The test bench, illustrated in Figure 10, consists of a heating camera (type Carbolite PF120/200), a cooling camera (type Derby F26LT), temperature sensors (placed inside the heating/cooling camera) and data acquisition system.

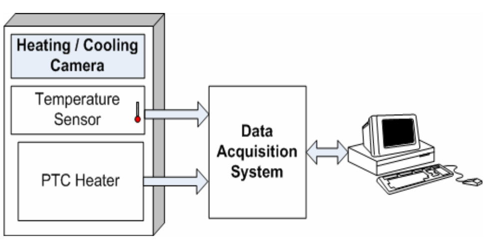


Fig. 10. *Test bench scheme implementation*

The PTC heater sample of 900 W/12 V was tested. In Figure 11, there is shown the electrical diagram for a 900 W PTC heater. The PTC heater is supplied at 12 V and the power levels are selected by using K1 and K2 relays.

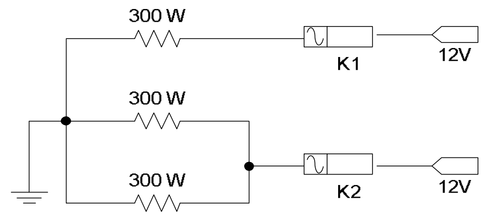


Fig. 11. *900 W PTC heaters*

The experimental results are illustrated in Figure 12.

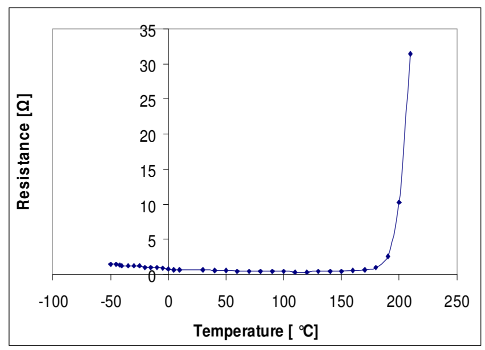


Fig. 12. *Resistance - Temperature characteristic curve of 900 W PTC heaters*

The data obtained show that the resistance initially decreases with increasing temperature. In that range, the resistance curve has a negative temperature coefficient. The minimal value of the resistance was 0.367 Ω, reached at 120 °C. At 120 °C, the negative temperature coefficient is changed to a positive one.

The obtained values of the temperature coefficient of resistance (α) are:

$\alpha_{negative} = -0.0044$ K$^{-1}$ for negative slope;

$\alpha_{positive} = +0.937$ K$^{-1}$ for positive slope.

The values of the temperature coefficient of resistance characterize the thermal regulating process of a PTC heater.

Based on this coefficient a PTC heater can be properly designed.

## 5. Conclusions

The heat obtained by transferring the combustion heat from the modern vehicle engine to the cooling system of the ICE is not enough to heat the vehicle interior and it takes a long time to heat the passenger's compartment and to obtain quickly the thermal comfort of the passengers.

In order to improve the time of increasing the interior air temperature and to compensate for the lower engine coolant temperature, auxiliary devices are required, such as: positive temperature coefficient heaters and booster heaters.

The PTC heaters are ideal for thermal comfort control through their capacity of thermal self-regulation.

An advantage of these devices is also (especially during winter or rainy days) the quick removal of the condensed drops from the windscreen and the improvement of the visibility through it.

The disadvantage is that the vehicle must be fitted with a more powerful generator, which increases the fuel consumption and pollution. For this reason, more research has to be performed in order to reduce factors that affect our daily life.

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