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CONTROL ALGORITHM ENGINE COOLING SYSTEM WITH INCREASED COOLANT TEMPERATURE

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Abstract

The article presents the test stand dedicated to research the cooling system of elevated coolant temperature. The test stand was developed in the software simulation AmeSim and the corresponding model was built. The temperature of this liquid was increased to the temperature of boiling water, as a basic compound of the cooling liquid. This system was designed for the four cylinder diesel engine 4CT90 with indirect fuel injection system. Intensity of the cooling, protected against too higher pressure, were changed by switching short and large liquid circulation and one or two fans of the cooler. Overpressure inside the cooling system was limited to 0,2 MPa, the temperature inside the cooling system was increased to 125°C. It was shown that it is possible to maintain the assumed constant pressure in the system and obtain at the elevated temperature of the liquid, leading to increased economic efficiency of the engine. The control algorithm to use of specific control procedures of cooling intensity in the pressure cooling system was developed. In the software simulation and the model stand liquid temperature and pressure course in selected points of system were determined. The characteristics obtained in the simulation software, and the model stand were designated using the developed algorithm. The software simulation was used electronic controls, while the model stand manually was controlled.

Keywords: *: algorithm, combustion engines, cooling systems, higher coolant temperature, simulation*

1. Introduction

Internal combustion engines, which are characterized by low efficiency, are still commonly used for vehicle propulsion. Work is currently underway on the introduction of hybrid vehicles, but due to technical difficulties, their use is still the matter of the future. Therefore, research on the development of internal combustion engines in the direction of increasing efficiency and reducing toxic exhaust are still being carried [7].

In the piston internal combustion engines, the most popular means of cooling is the cooling liquid, which provides a more uniform temperature around the combustion chamber than direct cooling air. In case of exceeding the boiling point must be a corresponding increase of pressure [3 - 5].

Efficiency of liquid cooling systems can be improved by use of electronic control unit, as well as less intense cooling of the engine and thus reduction the heat loss [2].

2. Test stands for testing the cooling system at elevated coolant temperature

In AMESIM software was developed the model stand scheme expressed with the help of flowcharts and was performed calculations and simulations showing the courses of pressure and temperature for the assumed parameters of pressure [8]. The model of the cooling system was made on the basis of test stand solutions designed and built using the original components of diesel engine 4CT90 (Fig. 1). The primary source of heat of the test stand are three heating elements with different electrical power adjacent to the walls of each cylinder.

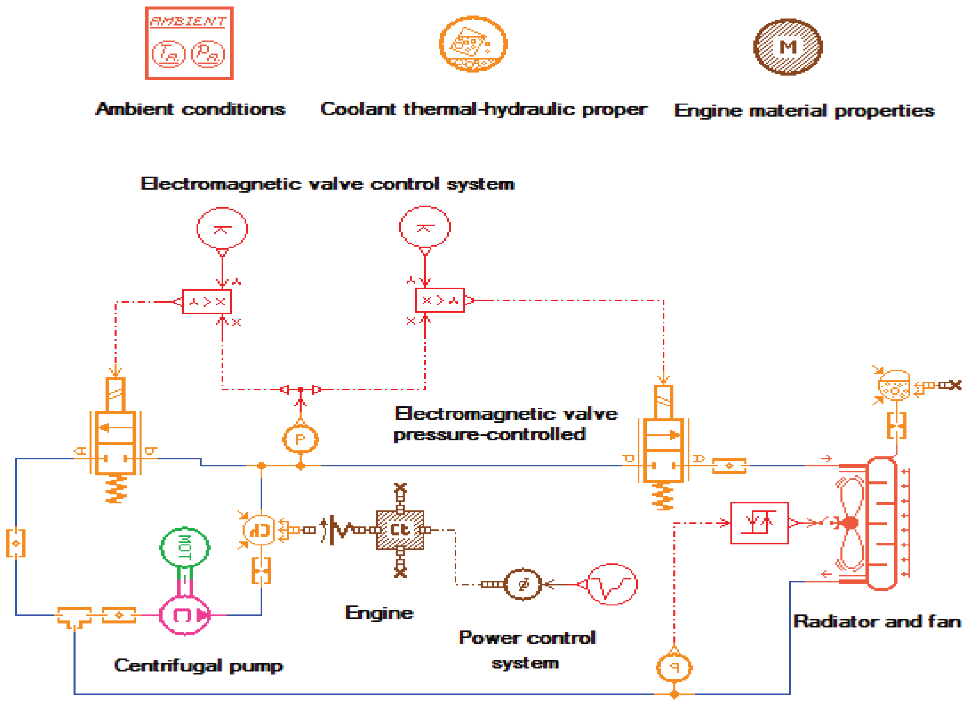


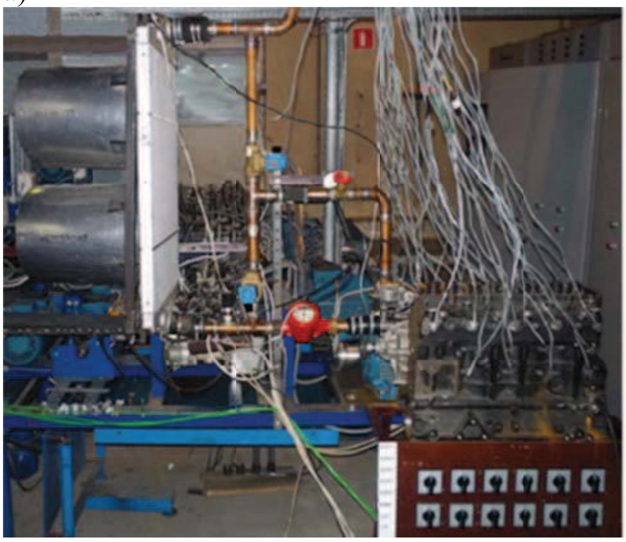
Fig. 1. Model stand scheme of cooling system developed in AMESIM software

In the presented model are elements which represent the engine block along with the system responsible for removing heat from the walls and transferring it to the coolant. The control system, through the change of power of heating, enables regulation of heat which is discharged by the cooling system. Electrically driven centrifugal pump with adjustable speed was used. Because of that, cooling intensity was not related to the assumed engine speed. The flow of liquid between the short and large circulation was controlled by pressure regulated solenoid valves. In order to perform the calculation of the cooling circuit parameters (temperature and pressure of liquid, coolant pump flow, operational characteristics of pumps and valves), was necessary to introduce a large amount of data including, first of all, the liquid properties, material properties of the engine, environment parameters, the volume of liquid in a small and a large circulation, the mass of the engine, etc. Detailed information was introduced according to the requirements of the program.

The experimental stand was built using original elements and units of the 4CT90 engine (Fig. 2a). Thermal energy of combustion process was simulated by units of electric immersion heaters, installed in every cylinder, fed from the electric network (Fig. 2b). Immersion heaters had a length of the stroke of the piston and were divided into three segments with different power: the highest of any segment of the heater power had 2,5 kW, central one had 1,5 kW, and the lowest one had a power of 1 kW. The test stand was equipped with thermoelements located in the engine block and the head, as well as into thermoelements placed in the system of heat exchange with the environment.

Two cooling fans placed in the channels with the sensors to enable measurement of the temperature and the rate of air flow. Channels of cooling liquid during measurements were shielded with foam reducing losses of the heat. The centrifugal water pump was driven with the electric motor, which the rotation speed was controlled with the programmed inverter what enabled to control intensity of cooling by changing the coolant flow rate [4, 7]. Flow of liquid between the short and large circulation, was controlled by solenoid valves. The pressure in the system was measured with the electric manometer.

a)



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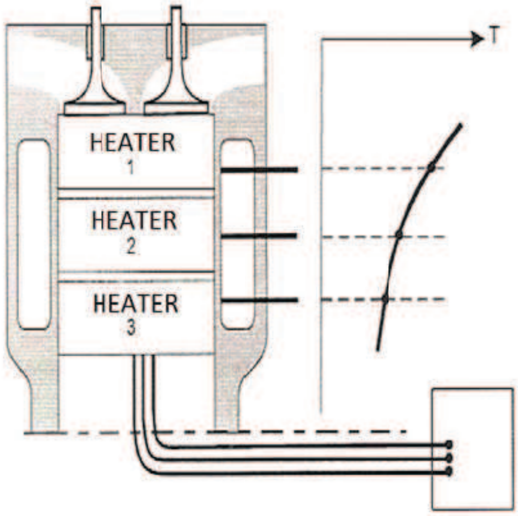


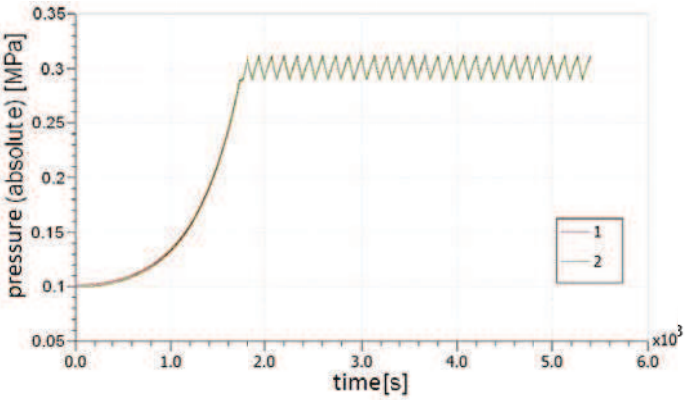
Fig. 2. The experimental research stand for cooling systems investigation: a) stand view, b) the heaters placement inside the engine cylinders [6]

3. Characteristics performed in the software simulation and on the model stand
3.1. Results of the simulation in AmeSim software

Simulations were performed for overpressure of 0,2 MPa at 80% of the filling with coolant at a total volume of 11 dm^3.

As a result of the simulation characteristics of the liquid temperature course before and after the cooler and the output from the engine, and the liquid pressure course in the short and full circulation were determined.

a)



For about 27 minutes followed the gentle increase overpressure of 0,2 MPa. After this time, it was necessary to maintain pressure on the average value of 0,2 MPa within 0,19 ÷ 0,21 MPa by changing the intensity of cooling (Fig. 3a).

At 80% of the coolant filling level, the temperature at the exit of the engine increased to 125°C, while at the exit of the radiator temperatures ranged 97°C ÷ 120°C (Fig. 3b). Courses characteristics due to switch between short and large circuits, the speed of the water pump and turn on and off the fan or fans, the pressure course was characterized by a relatively high homogeneity and stability throughout the heating cycle lasting about 100 minutes.

b)

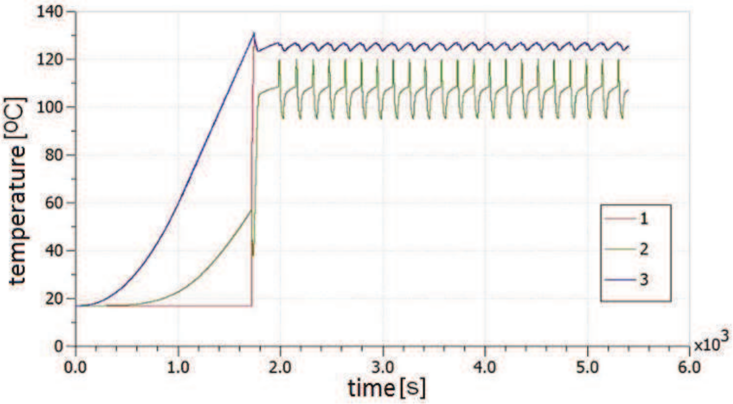


Fig. 3. Courses characteristics at the overpressure of 0,2 MPa and 80% of the coolant filling level: a) pressure: 1 - short circuit, 2 - large circuit, b) temperature: 1 - entrance to the radiator, 2 - out of the radiator, 3 - out of the cylinder block

3.2. Results on the model stand

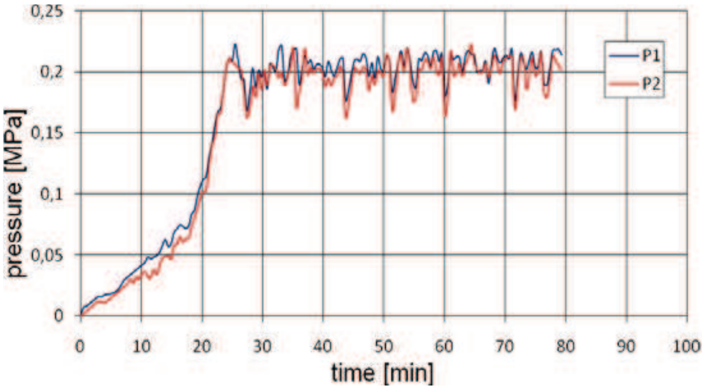
Experimental research was carried out on a model of diesel engine 4CT90 at the overpressure of 0,2 MPa and 80% filling of liquid system. The courses characteristics of coolants temperature before and after the radiator and the output from the engine, moreover the courses characteristics of coolants pressure in the small and large circulation were made.

The cooling system was heated up in the small system about 24 minutes when the pressure in the system received established value, the system switched from small to large circulation, resulting in pressure reduced to about 0,17 MPa, and its value ranged 0,17 ÷ 0,22 MPa (Fig. 4a). The temperature dropped about 10°C, but it was possible to achieve maximum value at 120°C (Fig. 4b).

Analyzing graphs of the simulation and experimental research, it is noted that the results are very similar, which indicates that the properly constructed simulation model mimics the action of the corresponding experimental engine cooling system. The characteristics show some differences, which may also derive from the fact that the mathematical model used an electronic control of all processes, whereas in studies of actual control takes place by hand.

As in the case of simulation characteristics courses result coming from switching between the short and full circulation, change the water pump speed, and turn on and off the fan or fans.

a)



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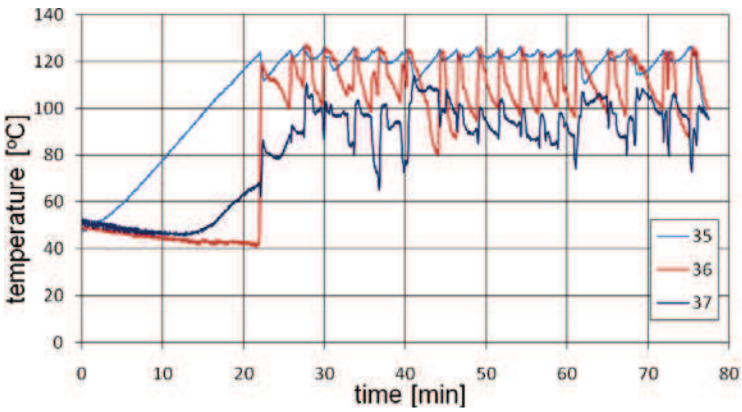

Fig. 4. Courses characteristics at the pressure of 0,2 MPa and 80% of the filling with coolant: a) pressure: P1 - small circuit, P2 - large circuit, b) temperature: 35 - out of the cylinder block, 36 - entrance to the radiator, 37 - out of the radiator

4. The working algorithm of the pressure cooling system

Cooling intensity at the model stand was controlled manually. Based on experience gained during this control, the algorithm was developed which enables the construction of the automatic control of cooling system [1].

Given control algorithm ensures the maintenance of assumed pressure, resulting in a rise in temperature. In a logical and efficient use of the individual controls on the engine cooling intensity, depending on the needs of the moment.

The algorithm assumes gradual of the various methods of changes in cooling intensity in the system until the moment when at all operating levels of cooling system, the pressure reaches a critical value in large circulation (Fig. 5).

When power is turned on the cooling liquid flows in the short circuit, after reaching assumed pressure, the system switches to a large circuit.

When the pressure drops below a set, the system switches back to the small circulation. When the system operates on the large circulation, the pressure control is done by increasing or decreasing the speed of the coolant pump.

Another level of control the intensity of cooling is switching on and off one or two fans. Despite work of two fans at the same time, still will be a further increase in pressure to achieve the critical pressure, the control system will give a signal to the decrease in load until the engine stops completely (in this case the electric heaters will be turned off).

The algorithm assumes a step regulation of the pump speed in order to simplify the algorithm. Modulating control (smooth) inverter operation is also possible, but requires the use of the controller with the possibility of analyzing the analog signal. If you need an easy way, by multiplying the number of blocks increase the speed of decision-making or to build a pump control algorithm continuously with appropriate parameters.

Marked pressure parameters can be determined depending on the physical properties of the system and therefore the algorithm is not given a specific value. These values can be stored in a separate table without having to type them into the algorithm.

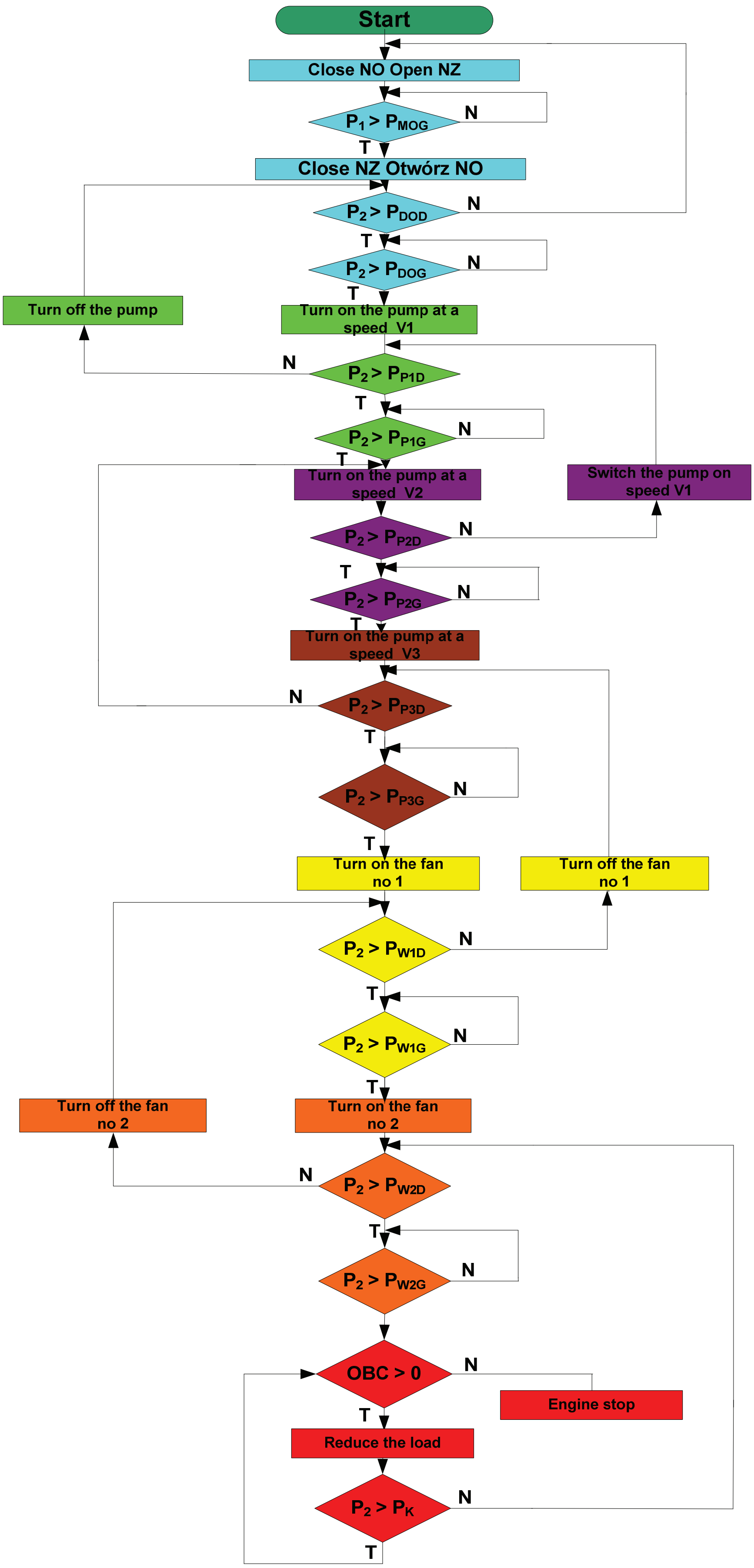

Fig. 5. The algorithm controls the cooling intensity

Tab. 1. Description of signs used in the algorithm

No.	DESIGNATION	DESCRIPTION
1	Blue color	The algorithm applies to control solenoid valves (switching between circuits, large and short)
2	Green color	The algorithm applies to the pump regulation at a speed of V_1 and open valve of the large circuit
3	Purple color	The algorithm applies to the pump regulation at a speed of V_2 and open valve of the large circuit
4	Brown color	The algorithm applies to the pump regulation at a speed of V_3 and open valve of the large circuit
5	Yellow color	The algorithm applies to the fan control No 1 with working pump on high speed and open valve of the large circuit
6	Orange color	The algorithm applies to the fan control No 2 with working pump and fan No 1 and open open valve of the large circuit
7	Red color	The algorithm applies to the system critical pressure control
8	P_1, P_2	Pressures measured in the short (P_1) and large (P_2) system
9	P_{MOG}	Established upper value of the pressure maintained in the short system
10	P_{DOD}	Established lower value of the pressure maintained in the large system
11	P_{DOG}	Established upper value of the pressure maintained in the large system
12	P_{P1D}	Established lower value of the pressure maintained in the large system at V_1 speed pump
13	P_{P1G}	Established upper value of the pressure maintained in the large system at V_1 speed pump
14	P_{P2D}	Established lower value of the pressure maintained in the large system at V_2 speed pump
15	P_{P2G}	Established upper value of the pressure maintained in the large system at V_2 speed pump
16	P_{P3D}	Established lower value of the pressure maintained in the large system at V_3 speed pump
17	P_{P3G}	Established upper value of the pressure maintained in the large system at V_3 speed pump
18	P_{W1D}	Established lower value of the pressure maintained in the large system with working fan No 1
19	P_{W1G}	Established upper value of the pressure maintained in the large system with working fan No 1

No.	DESIGNATION	DESCRIPTION
20	P_{W2D}	Established lower value of the pressure maintained in the large system with working fan No 2
21	P_{W2G}	Established upper value of the pressure maintained in the large system with working fan No 2
22	NO	Normally open valve
23	NZ	Normally closed valve
24	V_1-:-V_3	The pump speed
25	P_K	The critical pressure above which should reduce the load on the engine or turn off the engine
26	OBC	Engine load

5. Conclusions

As a result of simulation studies was found that temperatures can be maintained at nearly constant level in the block and head, and at the entrance and exit of the engine in this field of research. This means that one can control the system so it is possible to maintain the pressure and temperature at a given level and within acceptable limits.

During the studies the algorithm, which will allow to construct the automatic control of cooling system was developed. The algorithm ensures the sustaining of assumed pressure, resulting in a rise in temperature. In a logical and efficient use of the individual controls on the engine cooling intensity, depending on the needs of the moment.

The algorithm assumes gradual of the various methods of changes in cooling intensity in the system until the moment when at all operating levels of cooling system, the pressure reaches a critical value in the large circulation.

Adopting developed control algorithm of cooling intensity requires designing and building from scratch some bands of the pressure cooling system, for a very difficult and sometimes impossible task was to find existing standard components to the target system (eg pumps, flow meters, solenoid valves with adjustable bandwidth etc.).

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