IMPROVEMENT OF THE OPERATIONAL CHARACTERISTICS OF A VEHICLE COOLING SYSTEM USING A MECHATRONIC CONTROL SYSTEM

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Abstract: The operation of an internal combustion engine involves not only high mechanical loads but also critically high temperatures. To maintain the optimal operating temperature under such demanding conditions, the power unit is equipped with a cooling system. There are two main types of cooling systems: air cooling and liquid cooling. In liquid cooling systems, a radiator is used to dissipate excess heat from the engine; in some car models, there may be several radiators. An electric fan is mounted on this component.

When the engine is running, it generates a significant amount of heat. The cylinder block of a conventional internal combustion engine is designed with a cavity in its walls filled with coolant (cooling jacket). The cooling system includes a water pump driven by the crankshaft. This mechanism circulates the coolant through the system, thereby transferring heat away from the engine walls.

Keywords: naturally aspirated, GM Lacetti 1.5, engine cooling system, mechatronic control, fan, thermostat

Introduction:

Currently, one of the key areas in the production and maintenance of modern vehicles is improving the power and fuel efficiency of internal combustion engines (ICE). Enhancing the efficiency of heat exchange systems is a critical task in modern science and industry. Engine performance and its specific parameters are significantly influenced by operating conditions. These conditions have a complex impact on various performance indicators of the engine. As the coolant temperature in the cooling system rises, the temperature of the main engine components increases, altering the operating process parameters.

The internal combustion engine is a major factor negatively affecting the environmental performance of vehicles. A primary task for manufacturers in addressing this issue is to optimize engine processes. The development of engine technology is also focused on improving engine characteristics, such as increasing specific power output, durability, and reliability. The future of piston engines largely depends on their ability to adapt to new performance requirements.

The stable operation of any vehicle depends on both its operating conditions and the technical characteristics of the internal combustion engine. One of the most critical performance indicators is the engine's operating temperature. This parameter is influenced not only by ambient environmental conditions but also by various operational factors. If the engine temperature remains within the permissible range, it can deliver maximum power

IBAST | Volume 5, Issue 06, June

output over an extended period. Optimal engine operating conditions provide the best performance for all vehicle systems. [12]

A high temperature arises in the cylinder of the internal combustion engine due to the combustion of the fuel-air mixture. The temperature in the combustion chambers exceeds 2000 °C. The ICE design includes a cooling system and components that dissipate heat from working parts. Thanks to the stable operation of the engine's cooling system components, the engine temperature remains within an optimal range of +80 to 90 °C. Moreover, there are types of engines that operate at temperatures up to 110 °C, for which such temperatures are considered normal. This is most commonly found in engines with air cooling and turbocharging. [3, 4]

When the internal combustion engine operates within the optimal temperature range, the best conditions are created for its functioning:

- complete filling of the cylinders with the air-fuel mixture;
- stable engine performance during operation;
- reliable functioning of other vehicle mechanisms and systems.

Temperature indicators for the engine can be seen on the dashboard of any modern vehicle.

If the engine temperature exceeds its operating range, thermal stress cracks begin to change, leading to the following negative effects on engine performance:

- rapid wear of components;
- deformation and failure of mechanisms;
- significant reduction in engine power;
- risk of explosion in the power unit;
- premature fuel combustion.

If, during vehicle operation, the engine temperature is below the recommended range, this is a warning sign. At low temperatures, fuel-air mixture deposits form on the cylinder walls. If condensate from the air-fuel mixture enters the engine oil, it dilutes the oil and degrades its technical properties. With prolonged operation under such conditions, engine components wear out quickly and become unusable.

If the internal combustion engine does not reach its operating temperature, the vehicle should be taken to the nearest service center for diagnostics to avoid potential breakdowns.

No engine can operate without generating heat. Therefore, all components are subject to high thermal stress.

When the piston moves down to the bottom dead center, energy is expended and heat is released. The primary material used in engine construction is metal, which expands when heated, leading to thermal cracks. If these cracks worsen, engine failure may occur. To prevent such issues, an engine cooling system is used in internal combustion engines.

The operating temperature for gasoline engines should not exceed 90 °C. The purpose of coolant is to maintain the engine at its optimal temperature. The critical temperature for a gasoline internal combustion engine is 130 °C. If this temperature is reached, the engine may seize. Rising temperature causes the coolant to boil and evaporate. Under the influence of high heat, the size of engine parts changes significantly due to deformation, ultimately causing engine seizure.

Method and Materials:

IBAST | Volume 5, Issue 06, June

Calculation of the vehicle engine cooling system

When upgrading the cooling system of an internal combustion engine, a preliminary calculation is performed. However, this calculation is considered a trial or first-approximation estimate, aimed at preserving the geometric, thermal, and other parameters of the main cooling system components. This approach allows for the modified system to be maximally compatible with the existing design.

The initial value used in the calculation of the engine cooling system is the amount of heat Q_{sov} must be removed from the engine per unit of time. This value can be determined using the thermal balance equation:

$$Q_{sov} = q_{sov} \cdot N_e \quad (1)$$

where qsov - the percentage ratio of the amount of heat removed from the engine. For gasoline internal combustion engines qsov = 800-1300 KJ/KWh·s, for diesel internal combustion engines qsov = 1100-1150 KJ/KWh·s.

Having determined the value Q_{sov}, It is possible to determine the amount of liquid circulating in the cooling system per unit of time, $G_{sov} = Q_{sov}/C_{suy} \cdot (t_{chiq} - t_{kir})$, (2)

where Csuy - is the specific heat capacity of the circulating liquid.

Csuy for water = 4.22 KJ/kg·K, for ethylene glycol mixtures Csuy = 2-3.8 KJ/kg·K;

$t_{chiq} - t_{kir}$ - temperature of the liquid exiting and entering the radiator, °C.

For automotive engine radiators, the value is 5–10°C.

The engine cooling system is usually designed for two operating modes of the engine: at nominal power and at maximum torque.

Radiator Calculation

The size of the radiator's cooling surface (m^2) is determined by the following formula:

$$F_{rad} = 3600 \cdot Q_{sov}/ k \cdot (t_{sov\ suy} - t_{sov\ havo}), \quad (3)$$

k - overall heat transfer coefficient through the radiator walls,

$t_{sov\ suy}$ - average temperature of the coolant in the radiator, °C;

$t_{sov\ havo}$ - average temperature of the air passing through the radiator, °C

$$t_{sov\ suy} = t^{kir}_{sov\ suy} + t^{chiq}_{sov\ suy}/2, \quad (4)$$

$t^{kir}_{sov\ suy} = 90$ °C - coolant temperature at the radiator inlet;

$t^{chiq}_{sov\ suy} = 80\text{-}85$°C - coolant temperature at the radiator outlet;

$t_{sov\ havo}$ - the average temperature of the air passing through the radiator, ° C,

$$t_{sov\ havo} = t^{kir}_{sov\ havo} + t^{chiq}_{sov\ havo}/2, \quad (5)$$

$t^{kir}_{sov\ havo} = 40$ °C - air temperature at the radiator inlet;

$t^{chiq}_{sov\ havo} = 60\text{–}70$°C - air temperature at the radiator outlet

k The coefficient depends on many factors: the material of the cooling grille, the shape and condition of its internal and external surfaces, the nature of the airflow, etc. The radiator's

IBAST | Volume 5, Issue 06, June

thermal conductivity significantly deteriorates when oxidation, rust, or dirt forms on it.

The value of k can be determined by the following formula:

$$k = 1/1/\alpha_1 + \delta/\lambda + 1/\alpha_2, \qquad (6)$$

$\alpha_1 = 8500–14500\ KJ/m^2 \cdot K$ - heat transfer coefficient from the liquid to the radiator walls
δ – thermal conductivity coefficient of the metal walls (tubes) of the radiator. Value for brass $\delta = 300–450\ KJ/m^2 \cdot K$, for aluminum $\delta = 300–350\ KJ/m^2 \cdot K$, for stainless steel $\delta = 35–70\ KJ/m^2 \cdot K$;
λ – wall thickness of the tube, m;
α_2 - heat transfer coefficient from the radiator walls (tubes) to the air $\alpha_2 = 150–1100\ KJ/m^2 \cdot K$.

The coefficient α_2 mainly depends on the speed of the air passing through the radiator and is expressed as:

$\alpha_2 \approx 41 \cdot \omega_{havo}^{0.8}$.

For the initial calculation of the radiator surface area of the cooling system, the following formula can be used:

$$F_r = f \cdot N_e, \qquad (7)$$

f - special cooling zone, m^2/kVt.

For cars f = 0.14-0.3, for trucks f = 0.2-0.4, for tractors f = 0.4-0.55.
Size of the liquid cooling system l. (Ne kVt) varies within the following range: for passenger cars – (0.13–0.35) · Ne, for trucks– (0.27–0.8) · Ne, for tractors – (0.5–1.7) ·

Calculation of the water pump.

Calculated power of the water pump (sn):

$$G_{s.n} = G_\omega/\eta_{s.n} \ \text{kgs/h}, \qquad (8)$$

$\eta_{s.n}$ - coefficient accounting for the possibility of liquid leakage between the valve and the pump housing

Power required to drive the water pump:

$$N_{s.n} = G_{s.n} \cdot H/(75 \cdot 600 \cdot \eta_g \cdot \eta_{mex}) \ \text{kVt} \qquad (9)$$

$H=7$ *m. suv. usm.*— pressure generated by the pump;
$\eta_g = 0{,}65$ - hydraulic efficiency
$\eta_{mex} = 0{,}8$ - mechanical efficiency of the water pump

Considering that the parameters of the calculated and actual radiators are equal and can be accepted based on the available cooling system power, we do not calculate the dimensions and shape of the water pump.

Fan Calculation

The size of the fan for a car or tractor engine must be such that it provides an airflow sufficient to cool the liquid in the radiator.

The type of fan is determined by the conditional speed coefficient:

$$n_{sh} = n \cdot V^{0.5}_{havo}/H^{0.75}, \qquad (10)$$

V_{havo} - fan efficiency, m^3/s.

$$V_{havo} = Q_{sov}/3600 \cdot P_{havo} \cdot C_{havo} \cdot (t^{kir}_{sov\ havo} + t^{chiq}_{sov\ havo}), \qquad (11)$$

$P_{havo} = 1{,}07\ kg / m^3$ - air density;
$C_{havo} = 1\ KJ/kg \cdot K$ - specific heat capacity of air;
N - fan pressure. $H = 600–1000\ Pa$.

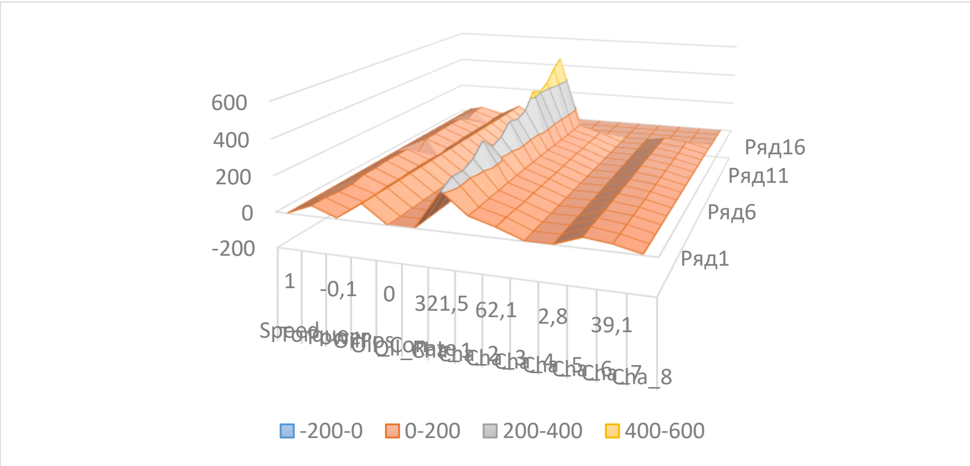
$n_{shart} = 15\text{-}100$ if there are centrifugal fans, $n_{shart} = 80\text{-}300$ If present, single-stage axial fans are used.

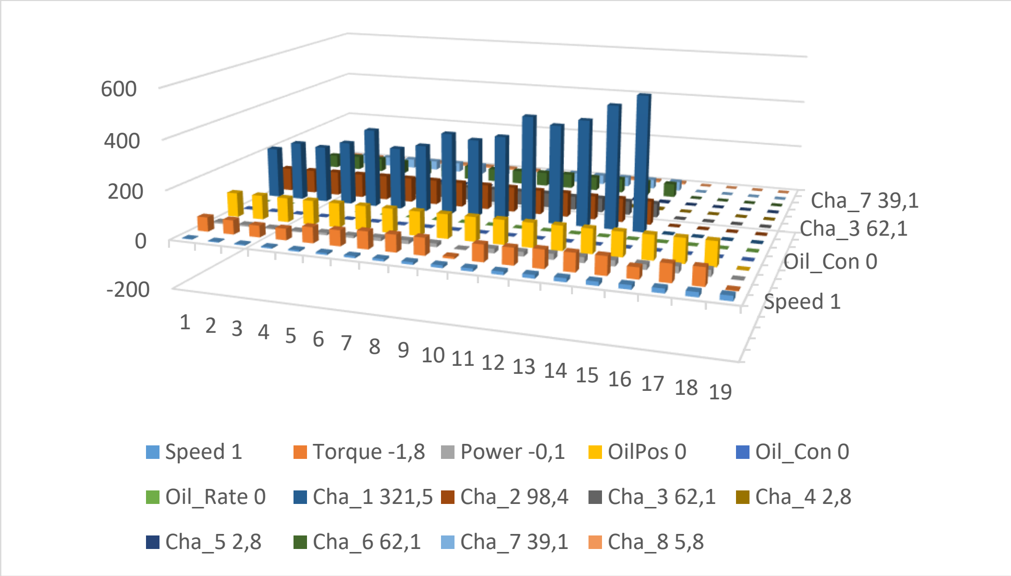
The "controller" subsystem includes a fuzzy logic controller that generates control actions based on a fuzzy logic output, which is used instead of a PD controller. Information about the imbalance has also been obtained. e=e(t), required by the fuzzy controller that manages the fan. T_{ref} and the actual T_{ref}.

Below is a dynamic test bench where experimental studies are conducted to validate the theoretical research in this field.

Figure 3. Hardware-software complex for the experimental determination of the dynamic characteristics of the internal combustion engine

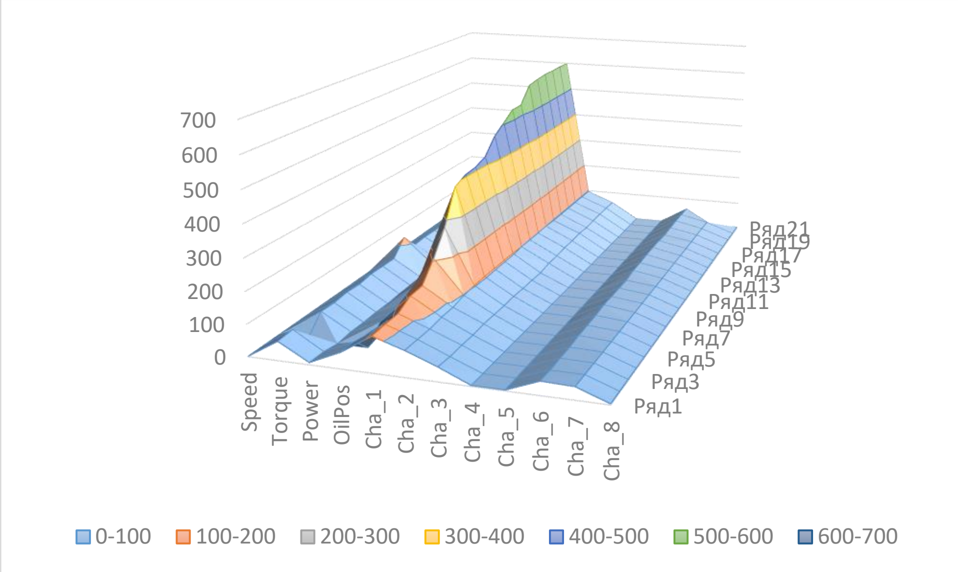
Figure 4. Diagnostic and measuring equipment used in this work for reading and calibrating mechatronic control systems of the engine and the vehicle [8].

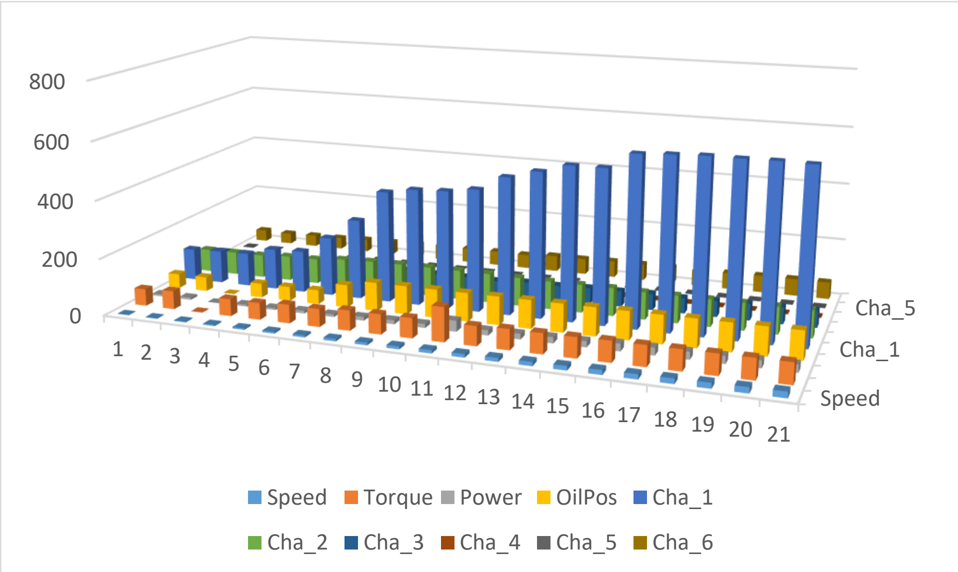




a)

Speed	Torque	Power	OilPos	Cha_1	Cha_2	Cha_3	Cha_4	Cha_5	Cha_6	Cha_7	Cha_8
1104,3	59,4	6,9	50	111	80,6	44,5	2,8	2,8	41,9	39,1	3,1
1102,1	64,1	7,4	50	115,1	81	41,4	2,8	2,8	39	39,1	3,1
769	0,9	0,1	0	117,3	81,4	43,7	2,8	2,8	41,2	39,1	3,1
1011,8	60	6,4	50	142,8	87,5	43,1	2,8	2,8	41,8	39,1	3,1
1000,9	59	6,2	50	146,9	88,6	47,2	2,8	2,8	45,8	39,1	3,2
1375,3	65,2	9,4	50	205,7	98	46,7	2,8	2,8	46,9	39,1	3,4
1331,9	63,1	8,8	80	279,4	101,9	45,9	2,8	2,8	48,3	39,1	3,5
1723,4	70,6	12,7	100	389,6	103,3	48	2,8	2,8	53,2	39,1	4
1884,9	69,9	13,8	100	407	102,8	45,9	2,8	2,8	51,5	39,1	4
1912,1	69,7	14	100	411,8	102,8	46	2,8	2,8	50,9	39,1	4,1
3035,8	119,9	38,1	100	426,6	102,8	44,1	2,8	2,8	49,6	39,1	4,1
2500	68,4	17,9	100	477,7	99,8	50,7	2,8	2,8	56,4	39,1	4,6
2555,5	71,5	19,1	100	505,4	99	50,7	2,8	2,8	56	39,1	4,8
2802,9	71,1	20,9	100	534,3	99	54,4	2,8	2,8	58,5	39,1	5
2803,7	71,3	20,9	100	535	99,6	54,8	2,8	2,8	58,7	39,1	5
3464,6	72,9	26,4	100	589,8	96,8	57,5	2,8	2,8	58,4	39,1	5,5
3467,5	72,5	26,3	100	595,7	96,6	54,2	2,8	2,8	54,9	39,1	5,5
3467,7	72,4	26,3	100	599,8	96,6	57,1	2,8	2,8	57,7	39,1	5,6
3465,7	72,6	26,4	100	599	96,5	59,4	2,8	2,8	59,9	39,1	5,6
3488,1	72,7	26,6	100	600,1	96,4	60	2,8	2,8	60,4	39,1	5,6
3491,9	72,8	26,6	100	597,9	96,3	59,4	2,8	2,8	60,2	39,1	5,6





б)

Conclusion

Based on the research results, the proposed mechatronic control system for the internal combustion engine cooling system, which implements fan control through an additional mechatronic adapter, smoothly adjusts the electric motor's rotation speed. This system is more reliable and efficient than traditional ones.

It is noted that the system, built on the basis of an integrated auxiliary mechatronic control system, manages the cooling of the internal combustion engine, maintains the engine's operating temperature with high accuracy, stabilizes the engine's thermal condition, thereby ensuring the achievement of the objective in a simple way.

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