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Estimation of the State of Engine of Mobile Machines in the Conditions of Operation on Basis of Onboard Diagnostics

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Abstract. According to the results of the analysis of literature sources, when the issue of determining the state of internal combustion engines is considered, a single basis at all stages of life has not yet been decided, because it is a complex problem. A feature that can solve this problem is the efficiency coefficient. To justify the efficiency of the engine as a parameter, at the design stage, a systematic approach was applied along with the definition of rank subordination and significance of all components with their representation in the form of functional and structural schemes. According to the schemes, there is the main system-forming component in the structure of engines, which in the operable state provides the conversion of thermal energy of the fuel into mechanical energy of the rotary movement of the engine shaft. All other components of the engine are intended to maintain the functioning of the main component of the internal combustion engine and to create comfortable operating conditions for the operator in the machine system where this engine operates. At the stage of completion of production of the internal combustion engine, bench tests are used to determine its condition on the basis of efficiency and all technical parameters of the engine. The efficiency of the internal combustion engine at the operational stage is ensured by the load of the hydraulic drive in the structure of the machines and the use of computer equipment that can remotely record diagnostic parameters.

1. Introduction

During the construction of railway structures, mobile machines are used, which include track, earthmoving and loading handling machines (TELHMs). The source of power for such machines is spark-ignition and diesel internal combustion engines, which require time-consuming and science-intensive research to determine their state under operating conditions. It is well known that if the state of the internal combustion engine during the operation of TELHM changes it results in decreased productivity and higher costs of fuel. It has been established that the technical and economic indicators of TELHMs are justified at the design stage, observed at the manufacturing stage and maintained in the operational stage, i.e., at all stages of life.

A feature that can characterize the state of the internal combustion engine at all stages of life of TELHMs must be relatively stable, sensitive to changes of the state, and the able to convert it into a signal for recording by modern measuring and computer equipment. The efficiency is accepted as such parameter [1] to determine the state of the internal combustion engine at all stages of life.

2. Analysis of recent studies and publications

According to the analysis of sources [2, 3, and 4], considerable attention is paid to determining the efficiency of TELHM engines. For instance, to determine the efficiency of engines in mass production, a variety of equipment and devices are used to measure the corresponding parameters. In particular, measurement and recording of such parameters as: – torque; – rotation speed of the



crankshaft; – fuel consumption for a given period of time, air; – the ignition or fuel injection advance angle; – water temperature, lubricant; – quality and chemical composition of the waste combustion products, and others.

The above parameters are determined on the test bench shown in figure 1.

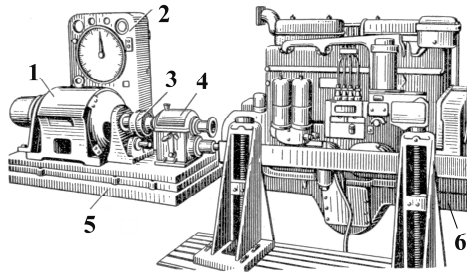


Figure 1. Test bench for diesel engines and determining of its efficiency: 1 – electric motor; 2 – control panel; 3 – elastic coupling; 4 – gearbox; 5 – foundation plate; 6 – mounting device.

So, according to [2], the value of the efficiency of the internal combustion engine η_e as an energy source for TELHMs is determined experimentally by the test bench method using the formula

$$\eta_e = (632 \cdot N_e) / (G_p \cdot Q_p), \quad (1)$$

where 632 is the heat equivalent, kcal/(h.p. hour); N_e is effective power, h.p.; G_p is fuel consumption, kg/year; Q_p is calorific value of fuel, kcal/kg.

According to the recommendation of the standard [3], the efficiency of the internal combustion engine η_e is based on the dependence

$$\eta_e = 3600 / (H_u \cdot g_e), \quad (2)$$

where H_u is lower range of fuel calorific value, which is 42.7 MJ/kg; g_e is specific fuel consumption, kg/(kW year).

According to modern studies [4], the efficiency of internal combustion engine η_e can be determined by the formula

$$\eta_e = 84,3 / g_e. \quad (3)$$

One of the necessary devices used in determining the efficiency at the stage of completion of production or after repair of the internal combustion engine is a special brake equipment, which is shown in the domestic design version figure 2 a) and in the foreign version figure 2 b).

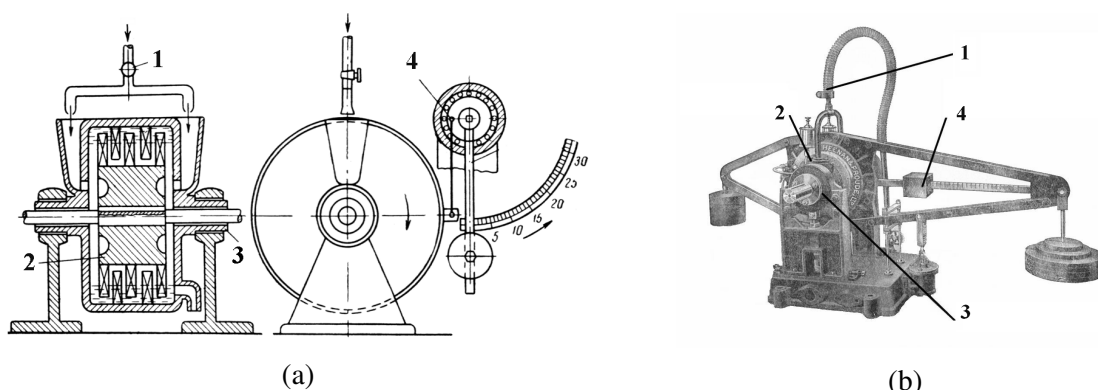


Figure 2. Hydraulic brake equipment: a) domestic brake design; b) foreign brake design; 1 – water supply pipeline; 2 – hydraulic brake; 3 – bearing support; 4 – torque weighing device. The braking equipment shown in figure 2 (a) and (b) is a component of the test bench that is used to generate torque on the internal combustion engine shaft to maintain a given engine speed when conducting appropriate experimental tests and acceptance tests in the laboratory.

3. Statement of the objective and tasks of the study

The purpose of this article is to assess the state of the internal combustion engine, as a component of the TELHM, at the engine design, manufacture and operation stage in terms of efficiency based on the use of on-board diagnostics.

The following tasks must be completed to achieve the above goal:

- using a systematic approach to the consideration of internal combustion engines and presenting its components as a system based on the rank subordination and importance of all components to improve the quality of engine design;
- justifying the process of on-board diagnostics of internal combustion engines by the efficiency directly in the structure of hydroficated TELHMs.

4. Problem solving

At the systemic level, the internal combustion engine [5, 6, and 7] is a system that is shown as simplified as possible, in figure 3.

So, at the stage of completion of production of the internal combustion engine, according to (figure 3), its output power N_{ex} (kW) is established by conducting bench test studies. To do this, on the test bench (figure 1), when braking equipment is used (figure 2), the torque on the internal combustion engine shaft M_{kr} (kN m) is determined and the angular velocity of the engine shaft ω_v (1/s) is measured.

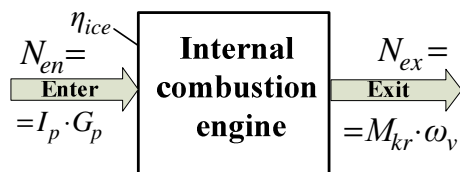


Figure 3. Schematic diagram of the internal combustion engine: N_{en} , N_{ex} is power input and output of the internal combustion engine; η_{ice} efficiency of the engine; I_p is fuel calorific value, kcal/kg; G_p is fuel consumption, kg/year; M_{kr} is torque, kN m; ω_v is angular speed of the shaft, 1/s.

Based on the results of the study, with a step-by-step increase in torque M_{kr} , thus changes in the angular speed of the shaft ω_v are recorded, which are further used to estimate the stepwise power output of the internal combustion engine, which is determined by the known dependence

$$N_{ex} = M_{kr} \cdot \omega_v \cdot \quad (4)$$

Simultaneously with determining the output parameters of the internal combustion engine based on the use of the test bench (figure 1) and braking equipment (figure 2), the value of the change in fuel consumption G_p (kg/year) is measured in steps at the input of the internal combustion engine, according to figure 4. Moreover, the known value for this fuel is its calorific value I_p (kcal/kg).

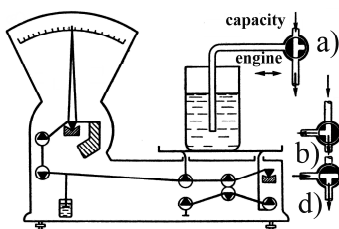


Figure 4. Measurements of the flow rate of fuel by weight in laboratory conditions: a) engine operation at fuel capacity (tank); b) the operation of the engine fuel tanks and filling of the measuring vessel; c) - operation of engine on fuel with a measuring vessel; d) - operation of engine on fuel with a measuring vessel.

When the parameters G_p and I_p are determined, power [6] at the input of the internal combustion engine N_{en} , (kW), is

$$N_{en} = (G_p \cdot I_p) / 3600. \quad (5)$$

Then, the state of the internal combustion engine in terms of efficiency η_{ice} at the stage of completion of production as an integral system is determined according to the dependence

$$\eta_{ice} = (3600 \cdot M_{kr} \cdot \omega_v) / (G_p \cdot I_p). \quad (6)$$

Thus, when bench tests of the internal combustion engine are performed, the following data are recorded: N_{ex} – engine output power; ω_v – angular speed of the shaft; G_p – fuel consumption; η_{ike} – engine efficiency. These results are specification data for a specific engine at the end of production or after its repair.

The structural components of the internal combustion engine [8, 9] are: power, cooling and lubrication systems. For example, the fuel system is designed to supply fuel and air to the working chambers of the cylinders. It also includes crank and gas distribution mechanisms. The cooling system is designed to maintain a balance between the temperature of the running engine and the fan-cooled radiator. The lubrication system is designed to reduce the loss of mechanical energy caused by counteraction of the forces of friction with the use of fan cooling of the oil cooler. In addition, the internal combustion engine includes an electric generator to supply power electrical appliances.

The main system-forming component in the structure of the internal combustion engine is the fuel system, which serves to convert the thermal energy of the fuel into mechanical energy of the rotating movement of the engine shaft. In addition, the internal combustion engine design includes contains additional components that ensure the maintenance of the main component of the engine. Additional components include the cooling system and the lubrication system with fan cooling of liquids. In addition, the structure of the internal combustion engine includes an electric generator, which creates comfortable conditions for the operator to work in the machine system where this engine operates. It should be noted that in the structure of each of these components, during their operation, energy losses occur to overcome the friction forces in the fuel, power supply and lubrication systems, and during the operation of the electric generator. At this stage of the study, the share of efficiency for energy losses directly to friction cannot be identified.

When applying the system approach, rank subordination and significance of the above-mentioned structural components of the engine as an integral system, the internal combustion engine can be represented in the form of two functional and structural schemes: – with a sequential connection of structural components, figure 5 a); – with a branched connection of structural components, figure 5 b).

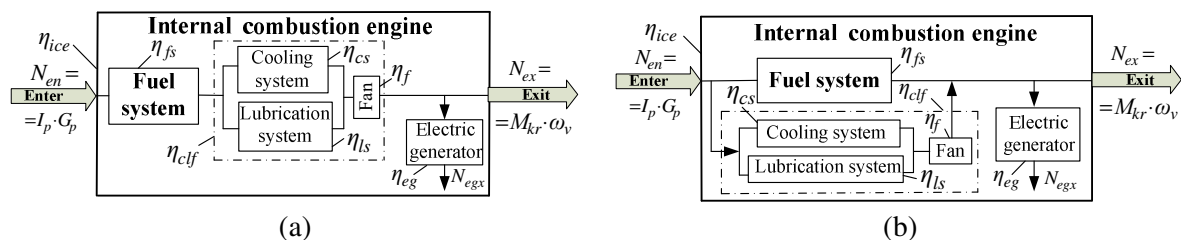


Figure 5. Functional and structural diagram of the internal combustion engine: a) – sequential connection of components; b) – branched connection of components; η_{fs} – coefficient of useful action fuel system; η_{elf} – coefficient of useful action cooling system, lubrication system, fan; η_{eg} – coefficient of useful action electric generator; N_{egx} – output power of the electric generator.

The engines shown in figure 5 (a) and (b) indicate possible relations between the components and the different nature of the energy distribution in the internal combustion engine structure. As shown in figure 3, determining the efficiency of the engine in general is not particularly difficult. At the same time, determining the efficiency of each separate component, namely the power supply, cooling and lubrication systems, is a complex issue.

However, an attempt to solve this problem can be successful if the experimental simulation method is used with a real engine design that is in operable condition. Based on the use of such an engine design, the operation of all its systems is simulated without using fuel, and with maximum compliance with the operating modes according to a special program for all engine systems. At the same time, each of these systems should be connected to special energy sources to drive the crankshaft and circulation pumps of the cooling system and lubricate the movable joints of the engine. It should be noted that the engine power system can be either in the static or in the dynamic mode, in which the

necessary parameters are recorded to determine the efficiency of the cooling system and the lubrication of the internal combustion engine.

At the same time, a special power source drives the crankshaft of the engine and ensures the operation of the cooling and lubrication systems. At the same time, if the specified engine operating modes are maintained, parameters are measured to determine the efficiency of the above systems. The efficiency of the η_{cs} cooling and lubrication η_{ls} system of the engine is determined by the formula

$$\eta_{cs} = (\eta_{ls}) = (N_{rs} - N_{nrs}) / N_{rs}, \quad (7)$$

where N_{rs} is the amount of power that is consumed in the operation of the cooling and lubrication systems of the engine when the specific conditions are maintained, and if these systems are connected to the special energy source, and given the fact that the power system is connected to the fuel tank, and cooling and lubricating systems are filled with relevant fluids, kW; N_{nrs} is the amount of power that is consumed in the operation of the cooling and the lubrication systems of the engine under the specific conditions, and if these systems are connected to the special power source, provided that the power supply system is disconnected from the fuel tank, and the cooling and lubrication are temporarily free from working fluid, kW.

According to the same methodology, the efficiency of the η_f fan and η_{eg} electric generator is determined using formula (7). The value of the efficiency of the unit η_{clf} as part of the η_{cs} cooling system and η_{ls} the lubrication system and the η_f fan is determined taking into account the diagram of connection, figure 5. Determining the efficiency of the η_{fs} power supply system is based on determining the efficiency η_{ice} of the engine as a whole.

The most difficult stage of determining the state of the internal combustion engine in terms of efficiency is the stage of engine operation in comparison with other stages of its life. At the present level of development of internal combustion engine design, the state of individual components is determined through the use of shared electronic unit in conjunction with sensors that record, in particular: – coolant temperature; – intake air temperature; pressure lubrication; mass air flow; – crankshaft; – camshaft position, and other sensors.

However, using these features seems to be impossible to be used to determine the engine state in terms of efficiency in the conditions of operation of an internal combustion engine as part of a CRVRM. In addition, modern TELHMs are usually equipped with a hydraulic system that provides the necessary level of engine load. Then the efficiency of the internal combustion engine η_e under operating conditions is determined based on the obtained dependence

$$\eta_e = (p_n \cdot V_n \cdot n_n \cdot 60) / (G_p \cdot I_p \cdot \eta_n), \quad (8)$$

where p_n is the fluid pressure generated by the hydraulic pump, mPa; V_n is the volume of the working chamber of the pump, cm^3/rev ; n_n is the rotating speed of the pump shaft, rev/min .; η_n is the total efficiency of the pump.

Since the parameters p_n and n_n can be maintained with high accuracy unchanged, and the parameters I_p and V_n are constant, the controlled parameter is the amount of fuel consumption G_p . The process of measuring fuel G_p consumption under laboratory conditions is shown in figure 4. For the operating conditions of the internal combustion engine, it is proposed to create a high-precision device for measuring fuel consumption for a given period of time and an electronic unit for determining the efficiency during the operation of modern TELHMs, based on dependence (8). The engine load to determine its efficiency by using the electronic unit on hydroficated TELHMs is provided by the use of flow regulators and other tools [10, 11 and 12].

Determining the actual value of the engine efficiency under operating conditions and comparing it with the initial value allows predicting further actions regarding the state of the internal combustion engine. It is known that if the efficiency of the internal combustion engine decreases or the engine fuel consumption increases by more than 5%, then the engine needs repairing.

5. The results of the calculation and their discussion

The presented results of the study suggest that the parameter of efficiency becomes a sign for determining the state at all stages of the life of the internal combustion engines which are part of various TELHMs. Further research in this area requires either the use of test bench equipment or the development of a new one or the use of modern measuring equipment to obtain new results with a minimum level of error.

6. Conclusions

Based on the results of the conducted studies, it was found that designing internal combustion engines according to a pre-specified efficiency value is a rather complex problem that requires further research. The most scientifically proven process for determining engine efficiency is the acceptance testing process. Currently, determining the efficiency of an internal combustion engine at the operational stage is of special scientific interest, since this is related to fuel economy in the operating conditions of modern TELHMs. It is known that if the fuel consumption increases by more than 5% or the engine efficiency decreases by more than 5% vs. the initial values, then such an engine should be sent for repair.

Timely determination of the efficiency value in the conditions of operation of the TELHMs based on the results of diagnostics of internal combustion engines will allow to repair them depending on their condition, instead of scheduled repairs and will reduce the operating cost of such machines and, accordingly, the construction cost in railway transport. In general, the economic effect can reach a significant value, which is further planned to be determined based on knowledge of all parameters.

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