

Directions of Development of Adaptive Systems to the Operating Conditions of Mobile Wood Chopping Machines with Low Power Engines

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Abstract. Wood choppers shredding branches equipped with low power drive units (up to 10 kW) are characterized by low technical sophistication. Their work translates into the consumption of non-renewable energy sources and the emission of toxic exhaust compounds into the environment. There are innovative technical solutions that allow you to increase the efficiency of chopping machines while reducing environmental impact. Such systems improve the adaptation of chopping machines working conditions to the demand for the branch cutting process. The article characterizes the innovative speed control system of machines loaded periodically variable. The fuel consumption model was presented and referred to the pilot fuel consumption results of a prototype equipped with an adaptive system. Benefits and development directions of the tested systems have been demonstrated.

1 Introduction

An increase in awareness of threats related to violating the standards for emission of harmful substances into the air, especially in large cities, enforces radical actions from politicians and local authorities. The directions of such works include reducing harmful anthropogenic emissions in cities [1], and natural cleansing of these areas by developing the infrastructure of green areas in the city [2,3]. Trees in such areas absorb exhaust fumes, dust and noise, and need to be cleared or trimmed [4]. The waste generated that way, in the form of branches, is processed by the machinery [5]. The processing mechanisms consist in shredding them so as to facilitate the further processes of transporting [6], storage [7], composting or generating power [8-11]. These machines are most frequently powered by combustion engines [12, 13] which consume non-renewable energy and release harmful exhaust gases [14,15]. They are harmful, in particular for their operators and their immediate surroundings [5].

Decreased energy consumption of wood shredding processes and reduced emission of exhaust gases generated by mobile shredding machinery indicate that there is a need for modifying their structure. In order to do that it is necessary to interfere in the structure of the system and the control algorithm of the chipper's engine [16,17]. A failure to take such actions in spite of compliance with the certification standards (which are far less strict than the ones set for motor cars) it is not possible to restrict the harmful effects of shredding

equipment on human life and health [18]. The authors recognize that mobile shredding machines adapt to the operating conditions to a limited extent, and the authors conduct R&D works on that subject [4,5,15,16].

The equipment shredding plant materials is being developed in many directions. They include research on cutting mechanisms [19, 20, 21] ovation in engines - mostly regarding combustion engines [22,23]. There are alternative types of fuel [14,24-28], innovative injection systems [17] and exhaust after treatment systems. The third group is adaptation systems increasing adaptation of the engine's operating parameters to the demand for active operation [15].

The article describes two adaptation systems for wood chippers. The first one, compliant with P.423369 patent application [29] is characterized by a change in rotational speed of the engine, depending on detection of branches in the feeding channel. The system does not recognize a change in engine load resulting from feeding with branches due to engine load recognized based on the signal from the throttle inclination angle. This results in decreasing the speed of rotation and operation of the combustion engine and a less favourable engine capacity specification area. The other described system is a system compliant with P.433586 patent application [30]. The structure is adapted to operation with a carburettor fuel system. The developed system recognizes and changes the rotational speed depending on branch detection. It also adjusts the rotational speed of the drive depending on the engine load, seeking to maintain the set parameters. Moreover, research results have been published for fuel consumption of a system compliant with P.423369 patent application and they have been compared to the developed model which enables determining fuel consumption.

2 Adaptive system compatible with fuel injection system, compliant with P.423369 patent application

The essence of the adaptation system compatible with the injection system consists in the method of controlling the rotational speed of the wood chipper drive with the spark ignition combustion engine (fig. 1). The engine control system depends on the value of signal from measurement sensors located in the feeding channel. Signals from the sensors detecting an object in the feed channel transfer information to the controller of the throttle, which commands the throttle lid location factor. Angular movement of the throttle lid and adaptation of the operating parameters in the engine controller, which sets a change of injection time, injection angle and ignition angle, result in a change in the rotational speed and torque of the chipper's drive, which allows for maximum power or shredding speed of the cutting mechanism (fig. 2). This status is maintained by the time the cut object gets behind the operating segment. This result is obtained by extending the time (allowing for movement of the object in the feed channel), by a defined fixed value in the throttle controller after receiving information that there is no object in the feed channel. Idle operation with rotational speed allowing for maximum engine torque or power is obtained at the cost of higher fuel consumption and higher exhaust fume emission. The process of controlling the drive while shredding is controlled by the engine controller. In order to maintain the set rotational speed and to achieve the necessary torque the unit controlling the combustion engine's operation changes the signals of injection time, injection angle and ignition angle by activating actuators such as fuel injectors and spark plugs. The value of torque demand during shredding varies and is generated depending on the shredded object. The machine starts returning to low rotational speed after a change of signal from sensors, which do not detect any objects in the feed channel. This is when the commanded throttle controller changes the angular position of the throttle, thereby reducing air supply to the combustion chamber. This leads to recording a change in the parameters of engine

operation by the combustion engine's controller and adjustment of fuel dose, and ignition targeted at maintaining a fixed, low rotational speed of the idle mode. This decreases fuel consumption and emission of exhaust fumes in the idle mode. The key of the aforementioned control mode is to introduce two idle operation modes and their automatic change, which enables adaptation the equipment to the operating conditions and, consequently, lower emission of exhaust fumes and lower fuel consumption.

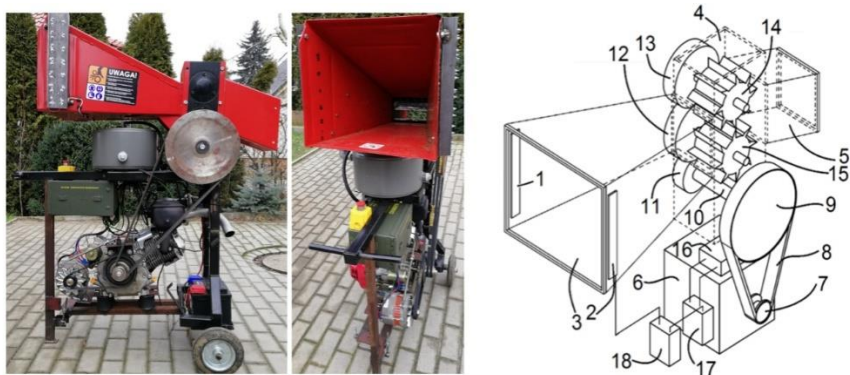


Fig. 1. Presentation of the maintenance-free and adaptive wood chip drive control system:
1 – object sensor in the working space (optical sensor – transmitter), 2 – object sensor in the working space (optical sensor – receiver), 3 – chipper feeding channel, 4 – housing of the member working pressure, 5 – outlet channel, 6 – spark ignition internal combustion engine, 7 – transmission pulley, 8 – transmission belt, 9 – driven transmission gear, 10 – drive shaft, 11 – gear drive wheel, 12 – the cogwheel driving the first mowing cutter, 13 – the cog wheel driving the second mowing cutter, 14 – the second mowing cutter, 15 – the first mowing cutter, 16 – the combustion engine internal control unit, 17 – electrically controlled throttle air, 18 – air throttle controller.

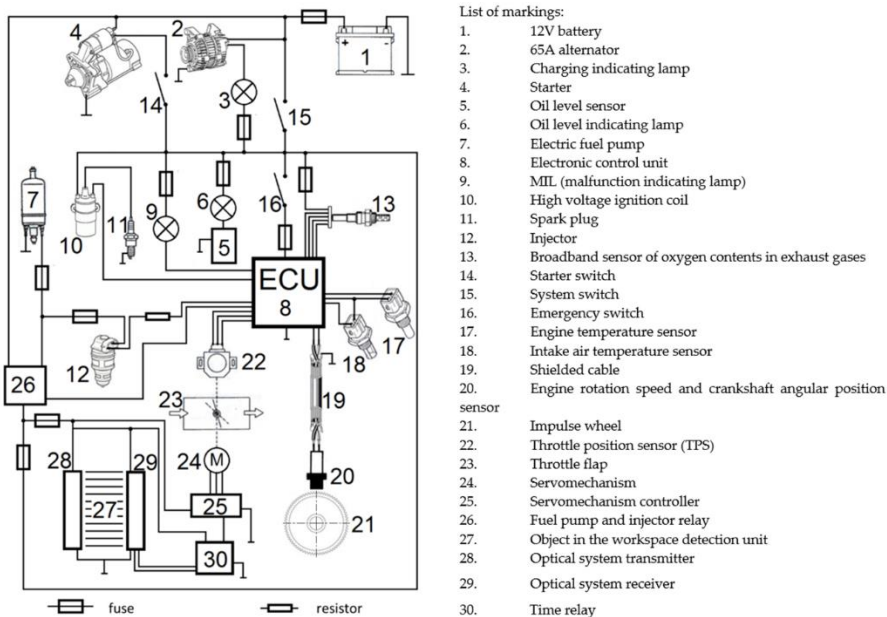


Fig. 2. Schematic of the innovative injection-ignition system used in the German GX390 with a maintenance-free detection and adaptive chipper drive control system.

3 Adaptive system compatible with carburettor systems for LPG and CNG fuels compatible with P.433586 patent application

The system described in P.423369 patent application (fig. 3) is the solution closest to the invention, taking into account the present state of technology. The system uses the detecting sensor in the chipper's feed channel, which works with the air throttle controller changing the angular position of the throttle lid. This system enables control without detecting engine overload. The conducted R&D works have shown that control of rotational speed taking into account changes in rotational speed resulting from overload of the system enables additional benefits (fig. 4).

The drive rotational speed control system of the spark ignition combustion engine wood chipper including a detection sensor in the feed channel and a throttle controller adjusting the angular position of the carburettor's throttle lid is the key element of the adaptation system compliant with P.433586 patent application. The throttle controller is connected to the stepper motor which works with a lever adjusting rotational speed. The lever is connected to the centrifugal mechanism adjusting the position of the throttle lid in the carburettor with a tie.

The wood chipper's drive includes a spark ignition combustion engine powered by combustion of air-fuel mixture. In the basic version air supplied from the environment flows through the air filter and is mixed with the fuel supplied from the fuel tank in the carburettor. Optionally, LPG gas might be supplied to the carburettor from a LPG tank, through a pressure regulator. CNG gas supplied from a CNG gas tank through a high pressure regulator and a low pressure regulator is another type of fuel that can be optionally supplied to the carburettor.

The rotational speed of output shaft of the spark ignition combustion engine depends mostly on the position of the throttle lid in the carburettor. The position of the throttle lid is set by the centrifugal mechanism through the first tie. The settings of the centrifugal mechanism are, on the other hand, set by the second tie, using a rotational speed adjustment lever. The position of the rotational speed adjustment lever can be changed with a stepper motor. The stepper motor is activated by a controller based on the signal from the sensors located in the chipper's feed channel. When an object is detected by the sensors in the feed channel, the chipper's rotational speed increases. After that, the controller sends changed position signal to the stepper motor, which changes the position of the rotational speed adjustment lever. Using the second tie, the rotational speed adjustment lever enables parting of weights in the centrifugal mechanism, which leads to a change in the position of the first tie and the throttle lid in the carburettor. If no branches are detected in the feed channel, low rotational speed is maintained in the chipper. A signal from the controller does not lead to a change in the position of the rotational speed adjustment lever, which prevents the weights of the centrifugal mechanism from parting, using the second tie. If the shredding machine operates with low rotational speed, it is idle operation mode, so operation adjustment depending on engine load is not assumed. Engine overload is common during operation with high rotational speed. Overload results in decreasing the engine's rotational speed and a change of the operation area which results from the engine's specifics. In the developed solution setting the rotational speed adjustment lever in the position of operating with high rotational speed enables smooth adjustment of the centrifugal mechanism to the set value. Decreasing the rotational speed resulting from engine overload has an impact on the centrifugal mechanism: it enables increasing the leaning angle of the centrifugal mechanism's weights and a change in the position of the throttle lid in the carburettor using the second tie. Additionally, a change to high rotational speed might be reduced by the controller after a signal from the oil temperature sensor is received. Low oil temperature has an influence on engine lubrication quality. In order to prolong the engine's life the

system might reduce operation of cool engine with overload and only allow for high rotational speed after the appropriate signal is received from the oil temperature sensor. The solution encourages supplying LPG gas to the carburettor through the pressure regulator from the LPG tank. The system also provides for an option of using CNG gas - in such case CNG gas is supplied from CNG gas tank to the carburettor through the high pressure regulator and the low pressure reducer.

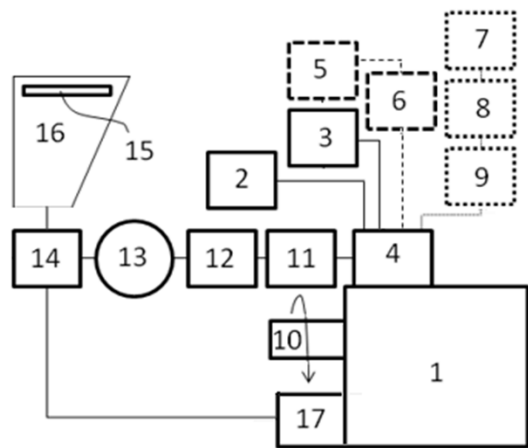


Fig. 3. Schematic diagram of the speed control system of wood chipper drive with a spark-ignition internal combustion engine; 1 – spark ignition engine, 2 – air filter, 3 – gasoline tank, 4 – carburettor, 5 – LPG gas tank, 6 – pressure reducer, 7 – CNG gas tank, 8 – high pressure reducer, 9 – low pressure reducer, 10 – output shaft, 11 – centrifugal mechanism, 12 – speed control lever, 13 – stepper motor, 14 – controller, 15 – sensors, 16 – supply channel, 17 – oil temperature sensor.

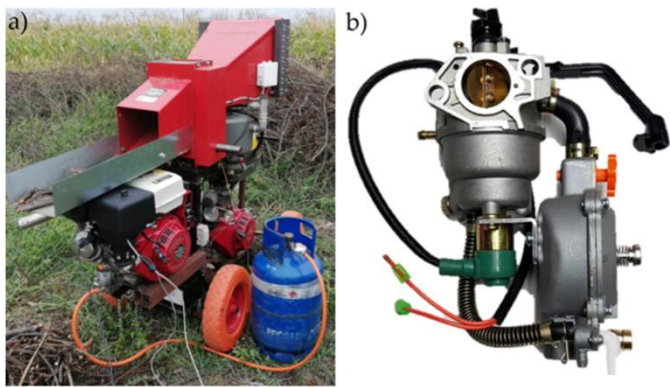


Fig. 4. Red Dragon RS-100 type cylindrical chipper: a) with German GX 390 type engine, b) carburettor powered by LPG; in the a) picture in the wood chipper two engines are mounted, but only the one connected to the cylinder took part in the tests.

4 Comparative analysis of fuel consumption: real life tests and theoretical model

The analysis is based on available research results, to which references can be found in the text. Therefore the authors do not describe the experiment in detail, they only refer to the results which are necessary in the analysis.

Based on the actual characteristics of time of the set injector opening signal (fig. 5) [4] during shredding processes with adaptation system, characteristic times for one shredding cycle might be set (t_{pc}). One such cycle includes idle time t_{iw} and active operation time t_c . Idle work time might be broken down into operation with zero injection time t_{w0} and operation with low rotational speed t_{ss} . Zero injection time means that the drive unit changes rotational speed from high to low, to which end it is necessary to reduce combustion processes in the engine. Active operation time can also be broken down into two characteristic modes: shredding time t_l , which means time of operation under load resulting from shredding branches which generate relatively high shredding resistance to the cutting mechanism and idle operation with high rotational speed t_{hs} , during which the load on the drive is relatively low, because thin branches are being shredded and the system is awaiting the next branch. If the system does not receive information on another object from the feed channel for approximately 2s, it reduces its operating speed to low.

$$t_{pc} = t_{iw} + t_c \quad (1)$$

$$t_{iw} = t_{w0} + t_{ss} \quad (2)$$

$$t_c = t_l + t_{hs} \quad (3)$$

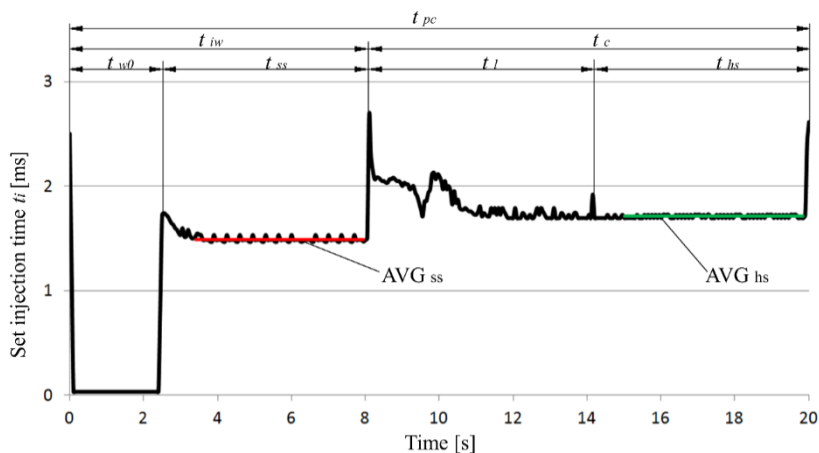


Fig. 5. Actual characteristics of the time of set open injector signal (drawn up based on [4]).

Based on the volume of injected fuel V in the function of time of the set injector opening signal t_w , rotational speed n and duration of the given phase, you can set average fuel consumption q_e .

$$q_e = n \cdot V(t_w) \left[\frac{L}{h} = \frac{rev}{h} \cdot \frac{L}{rev} \right] \quad (4)$$

The authors have defined a model to assess fuel consumption of chippers with drive units including adaptation system compliant with P.423369 patent application, based on the examined characteristics of time of the set injector opening signal (fig. 5). The model used for assessment of fuel consumption uses the average value of set injector opening signal time in three operation phases, where these are pre-set operation statuses (fig. 6). These are: time of operation with zero injection time t_{w0} , idle operation with low rotational speed AVG_{ss} and idle operation with high rotational speed AVG_{sh} . According to the equation (5):

$$q_e = n_{ss} \cdot V(t_{AVG_{ss}}) \cdot t_{ss} + n_{hs} \cdot V(t_{AVG_{sh}}) \cdot t_{hs} + n_0 \cdot V(t_{w0}) \cdot t_{tw0} \tag{5}$$

where:
 n_{ss} – low rotational speed (table. 1);
 n_{hs} – high rotational speed (table. 1);
 n_0 – average rotational speed during operation with zero injection time;
 $V(t_{AVG_{ss}})$ – volume of injected fuel, function of time of preset injector opening signal for the arithmetic mean during idle operation with low rotational speed in steady state (fig. 5);
 $V(t_{AVG_{sh}})$ – volume of injected fuel, function of time of preset injector opening signal for the arithmetic mean during idle operation with high rotational speed in steady state (fig. 5);
 $V(t_{w0})$ – volume of injected fuel, function of time of preset injector opening signal for the arithmetic mean during operation with zero injection time;
 t_{ss} – percentage share of operating time with low rotational speed;
 t_{hs} – percentage share of operating time with high rotational speed;
 t_{tw0} – percentage share of operating time without fuel injection;

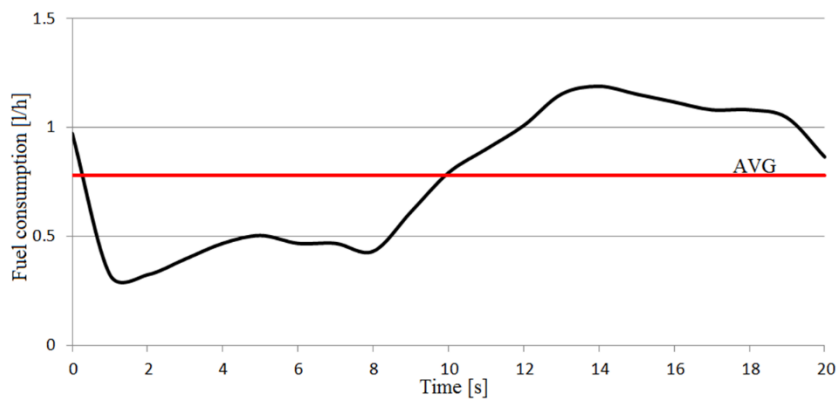


Fig. 6. Fuel consumption values set based on the model.

Table 1. Rotational speed and average fuel consumption of cylindrical wood chipper in selected, unchanged operating conditions (drawn up based on [4]).

Type of work	Rotation speed	Average fuel consumption
Idle operation at low speed	1700 rpm	0.43 l/h
Idle operation at high speed	4200 rpm	1.44 l/h

The assumed simplification allows to draw up the characteristics provided in figure 6. The value of fuel consumption set using the aforementioned methods might be referred to fuel consumption set based on the carbon audit determined at examining exhaust fume emission using PEMS [31] (fig. 7). When compared, fuel consumption for values preset in the model and actual values differ by approximately 15% (fig. 8). The model indicates lower fuel consumption, which is true as the characteristics of the signal of the set injector opening time (fig. 5) indicates areas of enrichment of the fuel mixture (higher fuel consumption) while changing the rotational speed and load on the system.

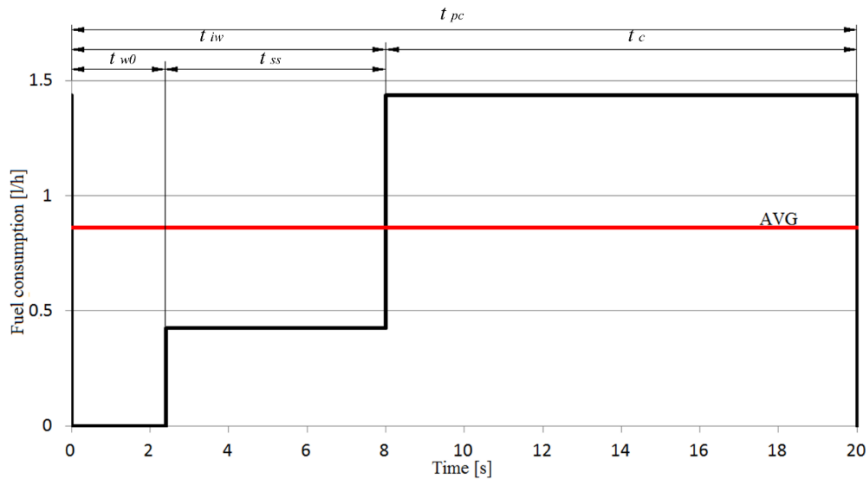


Fig. 7. Fuel consumption determined based on carbon audit defined at examination of exhaust fumes using PEMS (drawn up based on [31]).

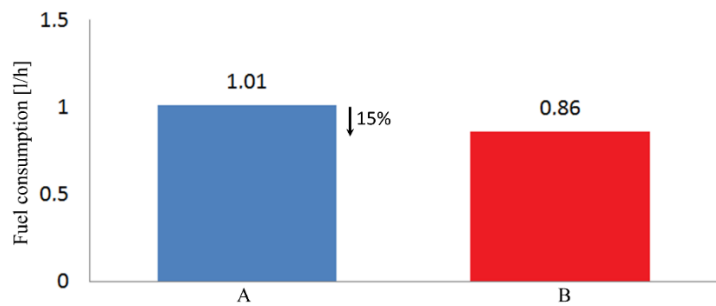


Fig. 8. Comparison of fuel consumption for the process of shredding wood with a chipper with adaptation system, where A - fuel consumption set based on carbon audit, defined at examination of exhaust fumes emission using PEMS, B - fuel consumption determined based on the model.

5 Summary

Adaptation systems that depend on the frequency of feeding with branches perform their functions during intermittent operation cycles. According to the specialist literature, branches fed by operators are shredded in this type of operation cycles [32, 5]. The used adaptation systems bring about tangible environmental and economic benefits due to a reduction in fuel consumption and emission of harmful exhaust fumes. Due to the diversity of fuel systems in low power engines (injection systems, carburettor systems, alternative fuel systems) adaptation system have various structures and specifications. They, however, offer a lot of benefits. Changes in rotational speed due to detection of branches in the feeding channel: reduce fuel consumption and emission of harmful exhaust fume compounds; decrease the operators' stress level caused by operating costs and ensure automatic adaptation to the operating conditions. Maintaining the set rotational speed (in particular when the drive unit is overloaded) guarantees operation with maximum power or torque of the machine. This is particularly important for shredding machines as insufficient torque while cutting branches results in stopping the cutting mechanism. The system reacting to delay caused by overload decreases the risk of blocking the cutting mechanism and improves the machine's capacity while overloaded, e.g. by allowing for shredding more branches at the same time. The system reacting to overload reduces the risk of stopping the operating segment due to overload and contributes to the machine's productivity as the reaction to decreasing the rotational speed due to overload is reduced, which optimizes production processes. It is possible to estimate fuel consumption based on average fuel consumption during operation with low and high rotational speed, taking into account the time when injection does not take place. The estimated values might give 15% difference in results and it should be assumed that the actual fuel consumption is higher. The developed structures fit the contemporary trend of structures supporting use of machines by way of adaptation to the operating conditions [33-39].

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