АВТОМОБІЛЬНИЙ ТРАНСПОРТ

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Changes in Engines Energy Indicators when the Cylinders are Disconnected in the Unloaded Mode of Operation

Researched regimes of engine operation without load: 1 – test of the original engine; 2 – test with disconnection of four cylinders by stopping the fuel supply; 3 – test with the disconnection of four cylinders by simultaneously stopping the fuel supply and the absence of pumping losses of the cylinder-piston group (CPG) of the disconnected cylinders. It was established that when the crankshaft rotation frequency increases from 1400 min^{-1} to 2550 min^{-1} when the fuel supply to half of the cylinders is turned off, the fuel economy changes from 0 to 0.53 kg/h. When the fuel is turned off and there are no CPG pumping losses, the fuel economy changes from 1.2 kg/h to 3.88 kg/h. Recommendations have been developed that allow to increase the efficiency of wheeled vehicles by 11-26% by disconnecting a part of the cylinders.

disconnecting cylinders, operation without load, pumping losses

Formulation of the problem. In the field of operation, when using wheeled machines, the tractor engine works for a considerable time at partial loads [1]. At a load of up to 50%, the engine works approximately 40% of the time, at a load of 50-65% – another 40% of the time, and only 20% of the time – at a load of 70% to full power [2]. In the conditions of real operation in farms, the time of engine operation at idle speed and light loads can be even longer, especially in the autumn and winter period. For truck engines, only 70-80% of the time is pure operation at an average load of up to 70%, and the rest of the time is for transport operations with an engine load of 20-30%.

Analysis of recent research and publications. The economic efficiency of diesel engines depends significantly on the degree of their loading. The highest values of efficiency are achieved in the nominal mode, and in the modes of low loads and idling, they are significantly reduced, which is associated with the deterioration of the mixture formation and fuel combustion, and the increase in the unevenness of the fuel supply [3, 4].

The feasibility of using this method is confirmed by numerous studies of tractor engines, however, this method has not yet found wide application in practice, partly due to the lack of justified modes of disconnection of an appropriate number of their cylinders and reliable devices for disconnection.

Setting objectives. The purpose of the study is to improve the performance of the engine in the no-load mode by substantiating the number of cylinder shutdowns and determining the energy parameters of its operation.

Achieving the set goal involves solving the following tasks:

– to determine the interrelationships of the operating indicators of the diesel engine at idle speed (no load) when half of the cylinders are disconnected;

– determine the nature of the influence of pumping losses in the CPG of disconnected cylinders on the energy parameters of the diesel engine at idle speed (no load).

Presenting main material. The operation of the engine at light loads and idling is, as a rule, characterized by deterioration of its main indicators. In this connection, there is need to improve the operation of the engine in these modes. One way is to disconnect part of the engine cylinders. In order to identify the effect of disconnection of a part of the engine cylinders on its operation, relevant studies were conducted at the Department of Mechanical Engineering and Machine Repair of the KhNAHU.

The study of the characteristics of the KamAZ-740 engine when part of the cylinders were disconnected was carried out on the KI-5274 stationary stand in the conditions of KHARZ-110 and KHARZ-126 auto repair production. The brake stand was equipped with measuring devices and control equipment according to GOST 14846-81 (ST SEV 765-77) [5] and included an electric balancing machine AKB 101-4. The parameters of the engine were determined in three variants of tests:

1 – test of the original engine;

2 – test with disconnection of four cylinders by stopping the fuel supply;

3 – test with disconnection four cylinders by the simultaneous cessation of fuel supply and the absence of pumping losses of the cylinder-piston group (CPG) of the disconnected cylinders. When the cylinder is disconnected and there are no pumping losses of CPG, the valves remain working, but a bypass valve is used for each cylinder, which is installed to the opening of the fuel injector. Test options in the figures are marked with numbers 1, 2, 3, respectively.

As is known [6], the indicator power of the engine N_i is the sum of the effective power $N_в$ and the power of mechanical losses N_{ml}

$$N_{in} = N_e + N_{ml}\text{, kW} \tag{1}$$

In the idling mode (no load), the effective power is zero [7], that is, all the power developed by the engine is spent on overcoming mechanical losses

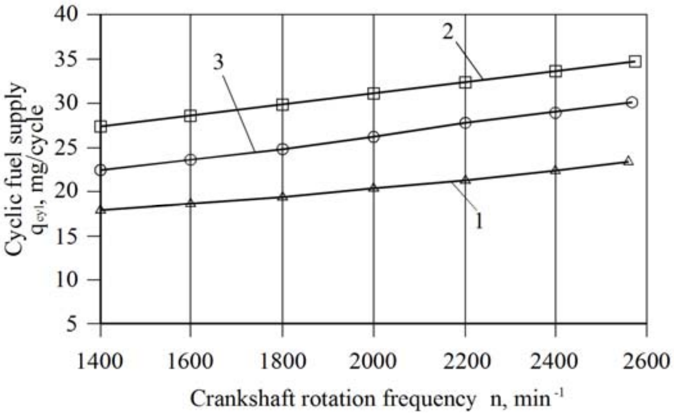
$$N_{in} = N_{ml}. \tag{2}$$

When the crankshaft rotation frequency increased from 1400 min^{-1} to 2550 min^{-1}, the engine parameters changed as follows.

Cyclic fuel supply q_{cyl} increases in all test options (Fig. 1), because in order to increase the frequency of rotation of the crankshaft, it is necessary to overcome the increasing power of mechanical losses, which is carried out by increasing the cyclic supply by increasing the active stroke of the plunger with the fuel supply lever.

When the cylinder was disconnected, only the cyclic fuel supply (curve 2) increased compared to the original version. This happened because when the fuel supply was turned off in cylinders 1 and 4 and 6 and 7, the engine power indicator decreased, while the crankshaft rotation frequency decreased, and to maintain them at the previous level, the cyclic supply with the help of the accelerator lever was increased by almost two times.

In the case of the option with the fuel supply cut off and the absence of pumping losses in the CPG (curve 3), the cyclic fuel supply is higher compared to the initial one, which is explained by the same reasons as the increase q_{cyl} when only fuel is turned off, and compared to the second option, it is lower, which is caused by a decrease in mechanical losses (pumping losses in the CPG have decreased).



1 – with all working cylinders; 2 – when the fuel supply is turned off in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders and the absence of pumping losses in CPG

Figure 1 – Dependence of cyclic feed on engine speed

Source: developed by the author

Hourly fuel consumption G_f is determined by the formula [6]

$$G_f = \frac{1,2\cdot q_{cyl}\cdot n\cdot i''_{cyl}}{10^4\cdot\tau} = g_i\cdot N_{in} = \frac{3600}{H_u\cdot\eta_i}\cdot N_{ml}, \text{ kg/h,} \tag{3}$$

where q_{cyl} – cyclic fuel supply, mg/cycle;

n – crankshaft rotation frequency, min^{-1};

i''_{cyl} – the number of working cylinders (for the second and third options i''_{cyl} =4, for the first i''_{cyl} =8);

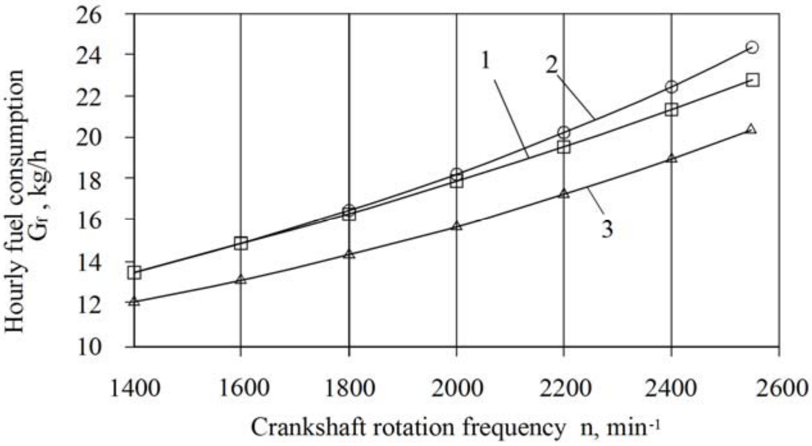
τ – the number of beats;

g_i – specific indicator fuel consumption, g/(kWh);

H_u – lower heat of combustion of fuel, MJ/kg;

η_i – indicator efficiency.

With an increase in the engine shaft rotation frequency, the time consumption of fuel increases in all test variants, which is associated with an increase in the cyclic supply q_{cyl} and with an increase in the number of cycles per unit of time n (Fig. 2).



1 – with all working cylinders; 2 – when the fuel supply is turned off
in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders
and the absence of pumping losses in CPG

Figure 2 – Dependence of hourly fuel consumption on engine speed

Source: developed by the author

When only the fuel supply is turned off (curve 2), the time consumption of fuel increases G_f from 1.83 kg/h at n=1400 min^{-1} to 4.97 kg/h at n =2550 min^{-1}, while the difference with the first option is between 0.0 and 0.5 kg/h. In the third option G_f increases from 1.33 kg/h to 5.11 kg/h, and compared to the first, the difference is from 0.41 kg/h to 1.1 kg/h. The decrease in hourly fuel consumption in the second and third options compared to the first is explained by the fact that when the fuel supply was turned off in some cylinders, the combustion process improved in others, caused by the improvement of evaporation (due to the increase in temperature), the increase in the range of the fuel jet, the improvement of atomization, and the reduction of uneven supply behind the cylinders due to an increase in the cyclic supply, that is, the indicator efficiency has increased. The greater decrease in variant 3 is due to the fact that, in addition to the improvement of the combustion process, there is a reduction in pumping stroke losses in the four-cylinder CPG drive.

Actual air consumption G_{air} is determined by dependence [6]

$$G_{air} = K\sqrt{\Delta h \cdot \rho_{air}}\text{, kg/h,} \tag{4}$$

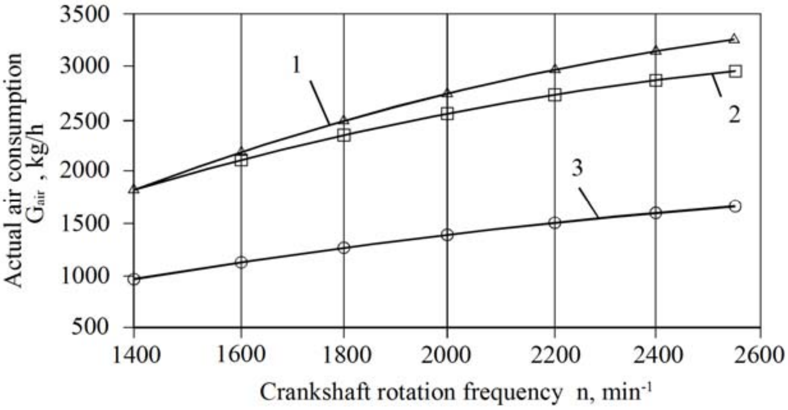
where K – constant measuring nozzle, K =24;

Δh – testimony U-like water manometer, shows the vacuum in the intake manifold, mm of water art.;

ρ_{air} – air density at ambient temperature (assumed to be constant), kg/m^3.

With 1, 2, 3 test options G_{air} increases (Fig. 3) due to increasing rarefaction in the intake manifold when the crankshaft rotation frequency increases.

With the 2nd option, the actual air consumption is slightly reduced. This is explained as follows: during the exhaust stroke during the overlap of the gas distribution phases, when the intake and exhaust valves are open, the outgoing exhaust gases draw fresh air into the cylinder, and since in this case there is no fuel supply to the four cylinders, there are no exhaust gases, then and the amount of actual air flow is therefore reduced due to bypass valves. When pumping losses are turned off in the CPG (curve 3) G_{air} compared to options 1 and 2, it is almost halved due to the fact that there are no pumping losses in the disconnected cylinders.



1 – with all working cylinders; 2 – when the fuel supply is turned off in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders and the absence of pumping losses in CPG
Figure 3 – Dependence of actual air flow on engine speed

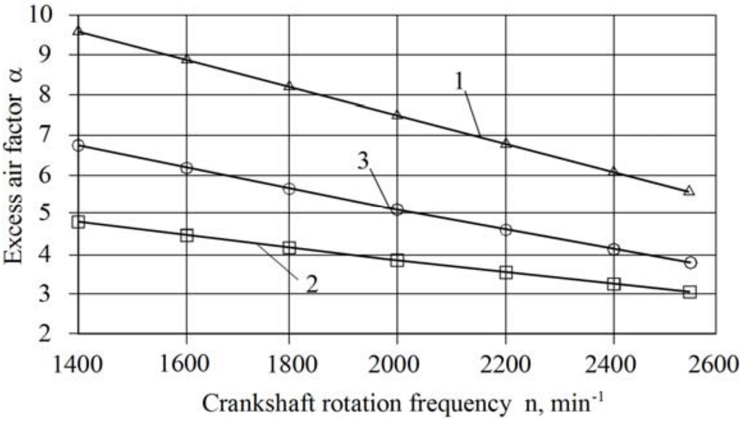
Source: developed by the author

Excess air factor α is determined by dependence [6]

$$\alpha = \frac{G_{air}}{G_f \cdot L_0}, \tag{5}$$

where L_0 – theoretically necessary amount of air for burning one kilogram of fuel, kg/kg.

With all test options α decreases (Fig. 4), as the growth rate of hourly fuel consumption G_f higher than the growth rate of actual air flow G_{air}. So, for example, with 1 option G_f increases by 4.01 times, and G_{air} in 1.97 times.



1 – with all working cylinders; 2 – when the fuel supply is turned off in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders and the absence of pumping losses in CPG
Figure 4 – Dependence of the coefficient of air excess on the frequency of rotation of the crankshaft of the engine

Source: developed by the author

In the second version of the tests, the coefficient of air excess is the lowest due to the fact that the amount of actual air flow is reduced by half, since mixture formation occurs only in half of the engine cylinders. In the third option α lower than that of the original engine due to the fact that with the shutdown of CPG pumping losses in the cylinder part, the air consumption decreases to a greater extent than the fuel consumption (at the nominal mode

G_{air} decreased by 2 times, and G_f by 1.3 times), but higher than when only fuel is turned off, which is due to the difference in fuel consumption for options 2 and 3 and the fact that G_{air} when the fuel is turned off differs from G_{air} when fuel is turned off and CPG pumping losses are less than 2 times. There is no dependence of the indicator efficiency on the coefficient of air excess in this case, since the value $\alpha \geq 3$.

Theoretical air consumption G_{Tair} is determined by dependence

$$G_{Tair} = 0,12 \cdot V_h \cdot i^{"}_{cyl} \cdot \rho_{air} \cdot \frac{n}{\tau} = C \cdot \rho_{air} \cdot n \cdot i^{"}_{cyl}\text{, kg/h,} \tag{6}$$

where V_h – working volume of one cylinder, l;

$i^{"}_{cyl}$ – the number of working engine cylinders (in this case, in options 1 and 2 $i^{"}_{cyl}$ =8, in the third $i^{"}_{cyl}$ =4);

C – constant (for a diesel engine $C = 0,12 \cdot V_h / \tau = 0,02034$).

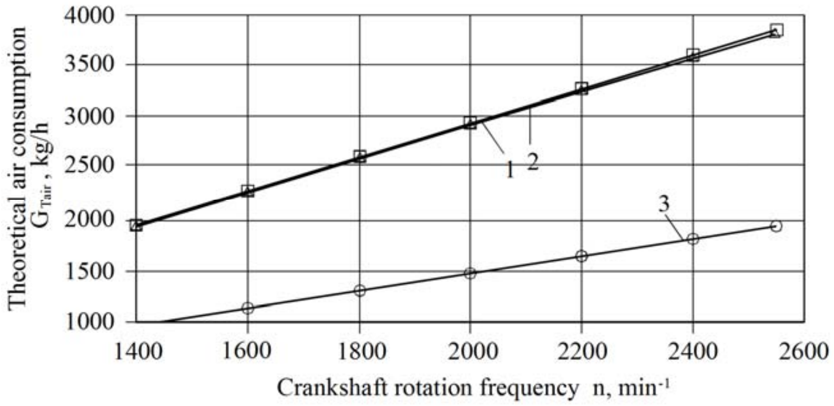
As can be seen from Figure 5, for all test options G_{Tair} increases due to an increase in engine speed n.

With 1 and 2 variants of tests G_{Tair} the same when the cylinders are turned off, according to option 3, it decreased by 2 times due to the absence of pumping losses in cylinders 1 and 4 and 6 and 7.

Fill factor η_v is equal to the ratio of actual air flow G_{air} to the theoretical G_{Tair}

$$\eta_v = \frac{G_{air}}{G_{Tair}}. \tag{7}$$

For all test options η_v decreases (Fig. 6) due to the different rate of change of actual and theoretical air flow (for option 1 G_{air} increases by 1.71 times, G_{Tair} increases by 1.96 times). Declining growth rate G_{air} is explained by a decrease in air density due to heating in the intake manifold and an increase in temperature with an increase in engine crankshaft rotation frequency, as well as due to an increase in aerodynamic losses.

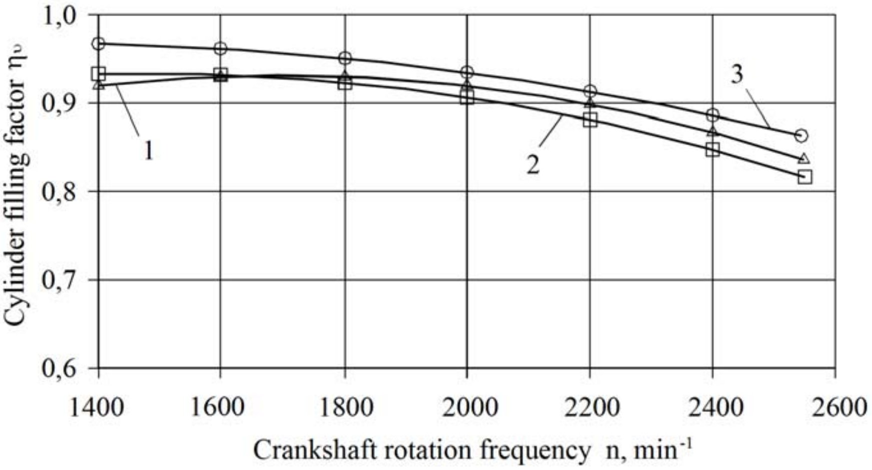


1 – with all working cylinders; 2 – when the fuel supply is turned off in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders and the absence of pumping losses in CPG

Figure 5 – Dependence of theoretical air flow rate on engine crankshaft rotation frequency

Source: developed by the author

In the variant with no pumping losses in the CPG, compared to the original engine, the filling factor increased due to the fact that the air is heated only in four cylinders, as opposed to eight, and also due to the reduction of aerodynamic resistance at the intake.

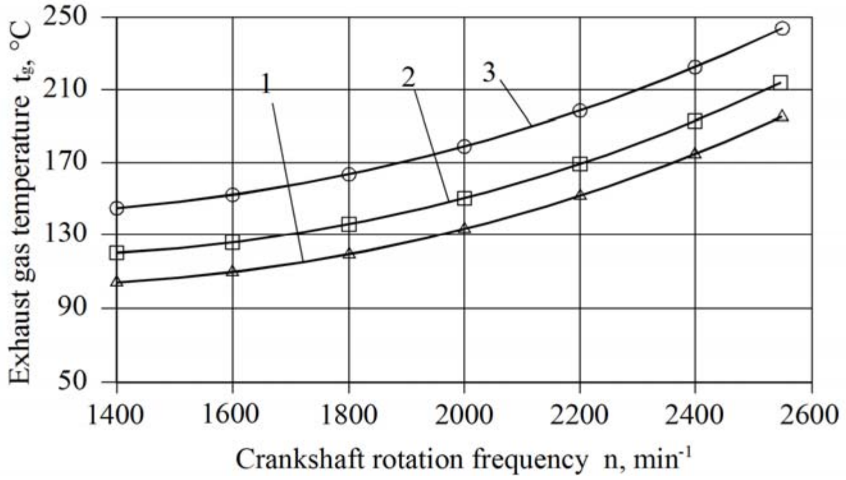


1 – with all working cylinders; 2 – when the fuel supply is turned off in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders and the absence of pumping losses in CPG

Figure 6 – Dependence of the filling factor on the engine crankshaft rotation frequency

Source: developed by the author

Exhaust gas temperature t_g increases in all variants (Fig. 7), since the amount of heat introduced per cycle increases (by increasing the cyclic supply), heat losses decrease (with a decrease in the cycle time), afterburning continues at the output stroke (due to a decrease in the time of the combustion process).



1 – with all working cylinders; 2 – when the fuel supply is turned off in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders and the absence of pumping losses in CPG

Figure 7 – Dependence of exhaust gas temperature on engine crankshaft speed

Source: developed by the author

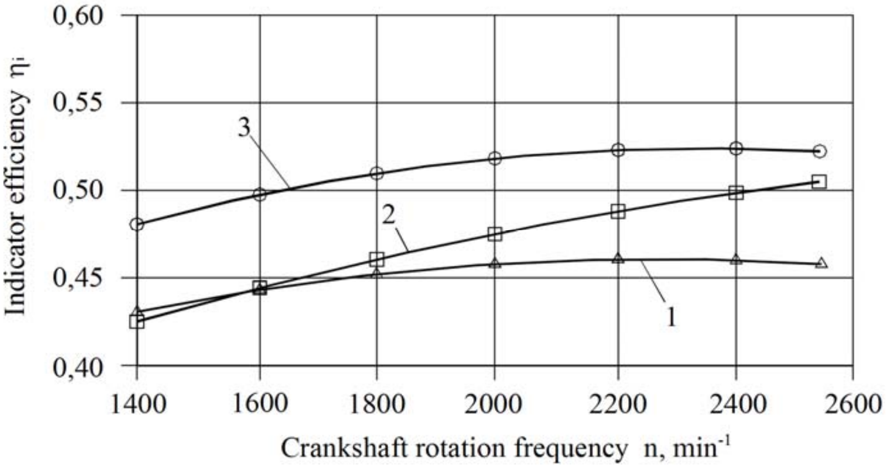
In the second and third options, the temperature of the exhaust gases t_g increased compared to the first, as the cyclic fuel supply increased, in the second option it is lower than in the third, since the exhaust gases coming out of the working second, third, fifth and eighth cylinders are diluted by air coming out of 1 , 4, 6 and 7 cylinders.

The indicative efficiency is determined by the formula

$$\eta_i = \frac{P_i \cdot L_0 \cdot \alpha}{H_u \cdot \eta_v \cdot \rho_{air}}, \tag{8}$$

where P_i – average indicator pressure, MPa.

Indicator efficiency depends mainly on P_i and α, and increases with all test options to a certain frequency (Fig. 8), since the rate of increase of the average indicator pressure exceeds the rate of decrease α, and at *n* above this frequency, the indicator efficiency slightly decreases, because the rate of decrease α becomes higher than the growth rate P_i.



1 – with all working cylinders; 2 – when the fuel supply is turned off in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders and the absence of pumping losses in CPG

Figure 8 – Dependence of the indicator efficiency on the engine crankshaft rotation frequency

Source: developed by the author

In the second option η_i increases, compared to option 1, due to the improvement of the processes of mixture formation and combustion.

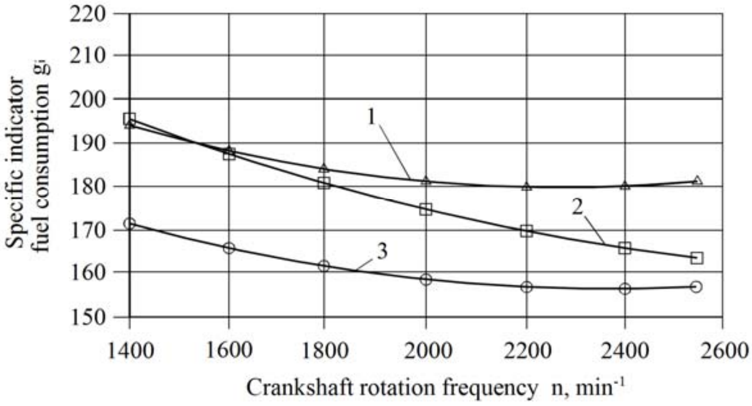
In the third version of the tests η_i higher, compared to the others, due to a two-fold increase in the average indicator pressure, although the excess air ratio decreased to 5.51.

Specific indicator fuel consumption g_i is determined by dependence

$$g_i = \frac{3600}{H_u \cdot \eta_i}. \tag{9}$$

The specific indicator fuel consumption decreases, as was said earlier, due to the improvement of the processes of mixture formation and combustion with an increase η_i (Fig. 9).

In variant 2 of the tests, compared to variant 1, the specific indicator fuel consumption decreases due to a decrease in hourly fuel consumption. In case of option 3 reduction g_i is carried out by increasing the average indicator pressure.



1 – with all working cylinders; 2 – when the fuel supply is turned off
in 50% of cylinders; 3 – with fuel cut off in 50% of cylinders
and the absence of pumping losses in CPG
Figure 9 – Dependence of the specific indicator fuel consumption on the rotation frequency engine crankshaft

Source: developed by the author

Conclusions.

1. Considered 3 variants of engine operation without load: 1 – test of the original engine; 2 – test with disconnection of four cylinders by stopping the fuel supply; 3 – test with the disconnection of four cylinders by simultaneously stopping the fuel supply and the absence of pumping losses of the cylinder-piston group (CPG) of the disconnected cylinders.
2. It was established that when the crankshaft rotation frequency increases from 1400 min^{-1} to 2550 min^{-1} when the fuel supply to half of the cylinders is turned off, the fuel economy changes from 0.0 to 0.53 kg/h. When the fuel is turned off and in the absence of pumping of CPG losses, fuel economy changes from 1.2 kg/h to 3.88 kg/h.
3. Recommendations have been developed that allow to increase the efficiency of wheeled vehicles by 11-26% by disconnecting the part of the cylinders.

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Зміни енергетичних показників двигуна при відключенні циліндрів в ненавантаженому режимі роботи

Робота двигуна на невеликих навантаженнях і холостому ходу характеризується погіршенням його основних показників. Виникає необхідність вдосконалення роботи двигуна на цих режимах. Одним із способів є від'єднання частини циліндрів двигуна.

В статті досліджено підвищення ефективності роботи двигуна в режимі холостого ходу шляхом обґрунтування кількості зупинок циліндра та визначення енергетичних параметрів його роботи. Були досліджені режими роботи двигуна без навантаження: 1 – випробування вихідного двигуна; 2 – випробування з відключенням чотирьох циліндрів припиненням подачі палива; 3 – випробування з відключенням чотирьох циліндрів одночасним припиненням подачі палива і відсутністю насосних втрат циліндро-поршневої групи (ЦПГ) відключених циліндрів.

Встановлено, що при збільшенні частоти обертання колінчастого вала від 1400 хв$^{-1}$ до 2550 хв$^{-1}$ при відключенні подачі палива в половину циліндрів економія палива змінюється від 0 до 0,53 кг/год. При відключенні палива і при відсутності насосних втрат ЦПГ економія палива змінюється від 1,2 кг/год до 3,88 кг/год. Розроблено рекомендації, які дозволяють шляхом відключення частини циліндрів збільшити економічність колісних машин на 11-26%.

відключення циліндрів, робота без навантаження, насосні втрати

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