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INCREASE DIESEL ENGINE PERFORMANCE BY TURNING OFF CYLINDERS

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Keywords: diesel engine, cylinder, fuel delievery, injector.
Abstract. The article analyzes the results of experiments to turn off the cylinders of various diesel engines at different loads. The most optimal modes have been identified in which cylinder shutdowns provide better efficiency.

УВЕЛИЧЕНИЕ ПРОИЗВОДИТЕЛЬНОСТИ РАБОТЫ ДИЗЕЛЬНОГО ДВИГАТЕЛЯ ПООЧЕРЕДНЫМ ОТКЛЮЧЕНИЕМ ЦИЛИНДРОВ

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Ключевые слова: дизельный двигатель, цилиндр, топливоподача, форсунка.
Аннотация. В статье проанализированы результаты экспериментов по отключению цилиндров различных дизельных двигателей при разной нагрузке. Выявлены наиболее оптимальные режимы, при которых отключение цилиндров дают лучшую экономичность.

Domestic agricultural tractors use diesel engines equipped with direct-acting fuel systems.

These engines operate most efficiently at revolutions and loads close to the nominal ones due to the fact that with a decrease in revolutions and loads, the fuel injection pressure (maximum and average) decreases sharply, and, as a result, the average diameter of the injected fuel drops (figure 1) [1], and, as a result, the completeness of fuel combustion and engine power are reduced, its lubricating oil is diluted, nozzle openings of the atomizer are coked, etc.

At the same time, low revs and loads for tractor diesels are quite characteristic. According to the data, for example, of the SIMSKh machine and tractor operation department, even in basic agricultural operations (plowing, etc.) 13% of the time the engines are idling and 7% are operating at lower crankshaft rotation speeds. When switching to operations such as transportation of goods, loading and unloading, spraying, fertilizing, etc. the share of work at low revs and loads increases significantly.

Improving the efficiency of engines under low load and idle conditions can be achieved by turning off part of the engine cylinders [2-4].

On the D-108 engine, for example, when idling, the fuel supply to the 2nd and 3rd cylinders is turned off. At the same time, the load on the remaining 1st and 4th cylinders increases, i.e. cycle feeds to these cylinders increase.

To ensure such a shutdown of feeds, the plungers of the high-pressure pump sections of the second and third cylinders are equipped with wider longitudinal by-pass grooves and cut-off edges with an increased oblique cut height [3].

Thus, the intersectional unevenness of fuel supply is artificially increased. In conventional engines, it increases with a decrease in the speed of the crankshaft and a decrease in cyclic feeds (Figure 2).

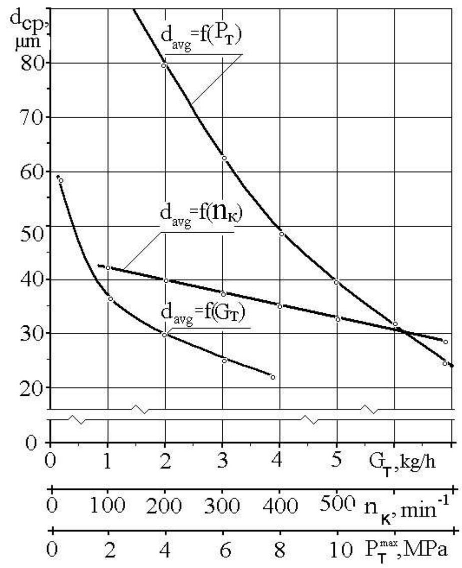

Fig. 1. Dependence of the average diameter of the injected fuel droplets d_{av} with the maximum injection pressure of the fuel system P_{tmax}, speed of the cam shaft n_k and hourly fuel con-umption GT (diesel D-35)

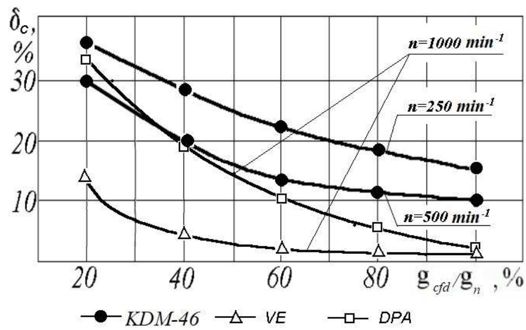

Fig. 2. Dependence of intersectional irregularities in the supply of systems with different pumps as a percentage of the ratio of cyclic supply (g_{cfd}) to its nominal value (g_n)

This method allows you to reduce the share of relatively roughly sprayed fuel corresponding to the beginning and end of injection.

At start-up, fuel is supplied to the cylinders by all sections of the high-pressure pump, i.e. diesel runs on all four cylinders. After starting, the rail of the fuel pump moves under the influence of the regulator, turning the plungers in the direction of decreasing the fuel supply. In this case, the enlarged grooves on the plungers of the 2nd and 3rd sections communicate with the bypass holes in the sleeves and the feeds to the 2nd and 3rd engine cylinders are turned off. The sections of the 1st and 4th cylinders continue to supply fuel, moreover, in correspondingly increased volumes.

In the case of engine operation with a load, the rail of the fuel pump moves (under the influence of the regulator) in the direction of increasing the flow of fuel. In this case, the holes in the sleeves of the 2nd and 3rd sections are overlapped by the working edge of the oblique cut of the plungers and, as a result, the sections of the 2nd and 3rd cylinders are also included in the work.

This method of turning off the cylinders when switching to idle mode has proven itself in the long-term operation of D-108 engines.

MTU (Germany), in order to optimize the design of engines of locomotives 12V956TB, introduced a sequential shutdown of the cylinders depending on the load (by upgrading 225 of these diesel engines). Disabling the specified cylinders for fuel supply and gas exchange (with fixing the gas exchange valves in the closed position). These measures simultaneously affected the boost pressure and allowed to reduce specific fuel consumption by 6.24%, carbon monoxide emissions by 63%, hydrocarbons by 84% and soot 86% [5].

The positive effect of turning off the cylinders during idling was also confirmed on the KamAZ-740 eight-cylinder engine [2]. And in this engine, turning off part of the cylinders (second and fourth) also reduced the gross emission of hydrocarbons and carbon monoxide. The annoying smell of exhaust gases also decreased. It turned out that the change in the emission of nitrogen oxides does not have an unambiguous connection with the shutdown of the cylinders; their release can both increase and decrease. It is interesting that the shutdown of the cylinders here was carried out by electromagnetic valves (connecting the high and low pressure lines). This method seems more promising, since it creates the possibility of alternating turn-off cylinders and, on the basis of this, reducing the heat load on the components and parts and increasing the mechanical efficiency engine.

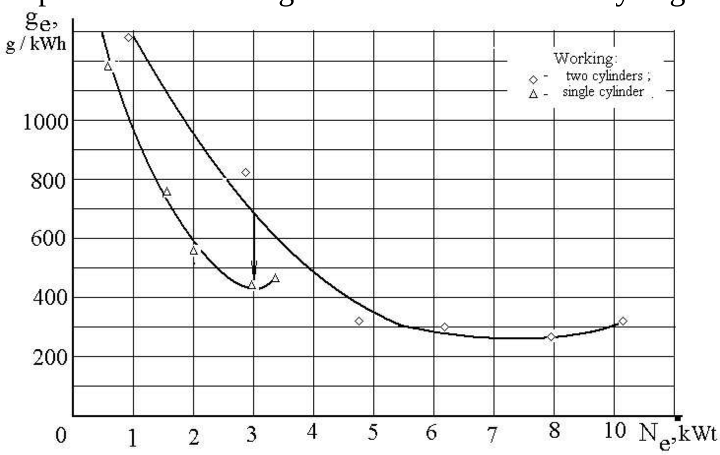

Fig. 3. Load characteristics of the D-21A engine at n = 1100 min-1

When one cylinder of the D-21A engine was turned off (tests were conducted on the KI-4893 GOSNITI break-in-brake stand) at the Ne = 3 kW mode, the specific fuel consumption decreased from 700 to 420 g / (kW · h) (Figure 2).

The D-240 diesel was tested on an MTZ-82 tractor mounted on a stand with KI-8927 running drums. The tests were carried out at 100, 75, 50 and 25% fuel supply and tractor operation at the third stage of the gearbox. The load on the driving wheels of the tractor varied smoothly with the help of a liquid rheostat in the generator circuit.

Taking into account the order of operation of the cylinders (1-3-4-2), 3.2 and 4 cylinders were sequentially disabled.

The degree of possible load on the driving wheels of the tractor decreased, of course, depending on the number of working cylinders (table 1).

The effect on the sequential shutdown of cylinders on the specific fuel consumption is demonstrated by the graphs of Figure 3.

It follows from them that with sequential shutdown of the cylinders, it is expedient to ensure the operation of the engine according to the characteristic a-b-c-d-d-e-f-z. In this case, significant fuel economy will be achieved as the effective power de-creases. So, in the case of operation at nominal and maximum torques and a decrease in power from 50 to 40 kW when one cylinder is turned off, the effective fuel consumption is reduced by 38 g / (kW · h), a decrease in power to 23 kW and off 2 x cylinders - additionally at 62 g / (kW · h), - up to 7 kW and shutdown of 3 - at another 78 g / (kW · h) (Figure 3).

Tab. 1. The degree of possible load of the tractor (and its engine) at work in 3rd gear and turning off the cylinders

The number of working cylinders	Possible tractor load (in kN) (in the numerator) and specific engine effective power (kW) (in the denominator) at rated and maximum torques on the motor shaft:	
	$Mt^{н}$	Mt^{max}
4	14/54,9	20/45,6
3	12,5/40,4	16/33,34
2	7,5/21,3	9/16,8
1	0,5/5,85	1,25/1,33

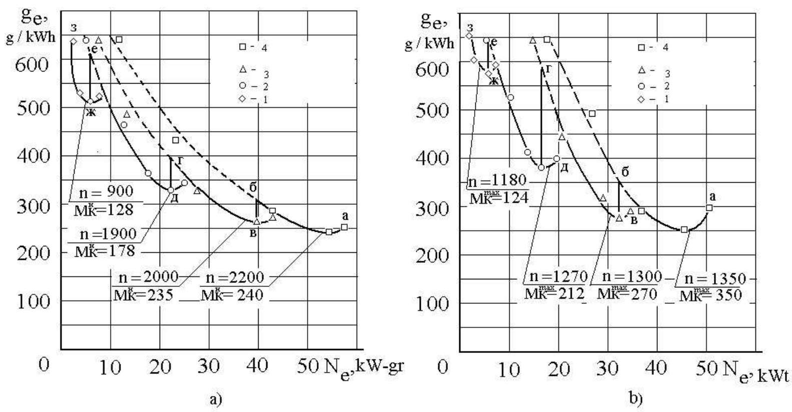

Fig. 3. Load characteristic of a D-240 diesel engine (solid curve) at nominal (a) and maximum (b) torques and operation on the 1st, 2nd, 3rd and 4th cylinders

An obstacle to the use of turning off the cylinders may be high values of the uneven rotation of the engine crankshaft and, as a consequence, of starting revolutions.

The results of calculations of the non-uniformity of rotation of the crankshaft and the conditional values of the starting revolutions of the four-cylinder diesel engine under consideration when operating on four, three, two and one cylinders are given in table 2. In the calculations, the moment of inertia of the flywheel was taken to be equal to the actual value I = 0.82 kg m2, and the conditional starting speed was determined by the expression:

$$n_{п} = k_z \cdot \frac{1}{\pi} \cdot \sqrt{\frac{L_{изб}}{\delta_{п} \cdot I}} \cdot 30;$$

where δ_p is the degree of uneven rotation of the crankshaft during start-up;

k_z - is the safety factor; take δ_p=2 and k_z = 2,41we get:

$$n_п = 16{,}26 \cdot \sqrt{\frac{L_{изб}}{I}} .$$

Tab. 2. The values of δ and np during sequential shutdown of the cylinders

The number of cylinders included	Indicators			
	Exact work L_{exc}, k_j	Coefficient of unevenness, δ	Conditional, $n_п$, min^{-1}	The values of the minimum stable idle speed, $g^{xx}_{e\,min}$, min^{-1}
4	0,124	0,004	200,00	396,00
3	0,201	0,008	254,63	504,18
2	0,392	0,010	355,60	704,09
1	0,522	0,012	410,35	812,49

The calculated values of the minimum stable idle speed amounted to 396 ... 550, the maximum idle speed 550 ... 660 min-1.

As you can see, as the cylinders are turned off, the uneven rotation of the crankshaft (and starting revolutions) increases; it becomes greatest when working on one cylinder - 0.012 (83). At the same time, it slightly exceeds the limits established for tractor diesel engines (0.004 ... 0.010). To reduce it to 0.01, it is enough, as calculations show, to increase the moment of inertia of the flywheel to 0.8856 kg · m2 (by 8%). In this case, turning off the cylinders will not worsen the dynamic performance of the D-240 engine. To achieve minimum starting revolutions (166 min-1) it will be enough to start the engine without turning off the cylinders.

The sequential shutdown of the engine cylinders as the load decreases can also be carried out in tractor diesels by corresponding profiling of the control edge of the plunger. However, in this case, in the case of operation for a long time, the thermal mode of the engine will be disrupted – mechanical losses and thermal stress of individual parts will increase. Therefore, here, it is more preferable to alternate the dis-connected (turned on) cylinders by applying electromagnetic valves (as in the above case of a KamAZ automobile engine).

In general, we note that the sequential shutdown of the cylinders most fully manifests its positive aspects (reduction in specific fuel consumption and exhaust gas toxicity, etc.) precisely in tractor diesels operating in wide ranges of revolutions and loads.

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